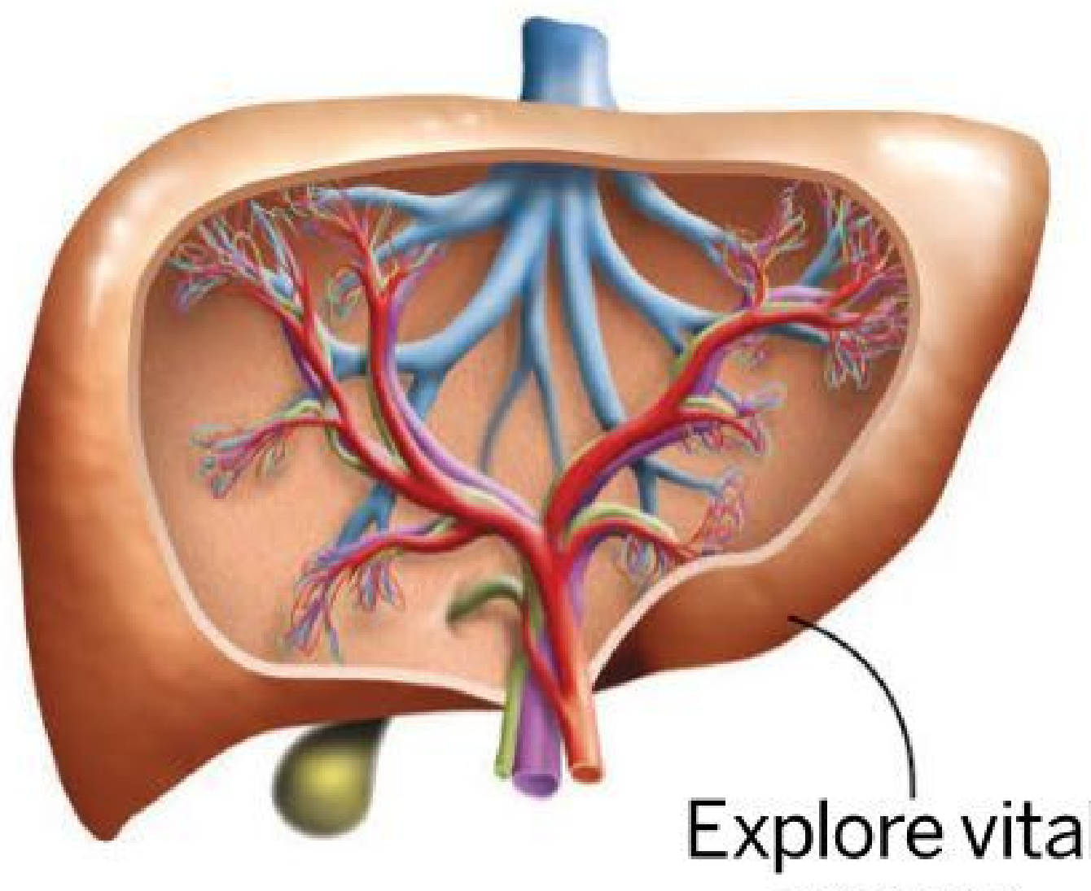
NEW

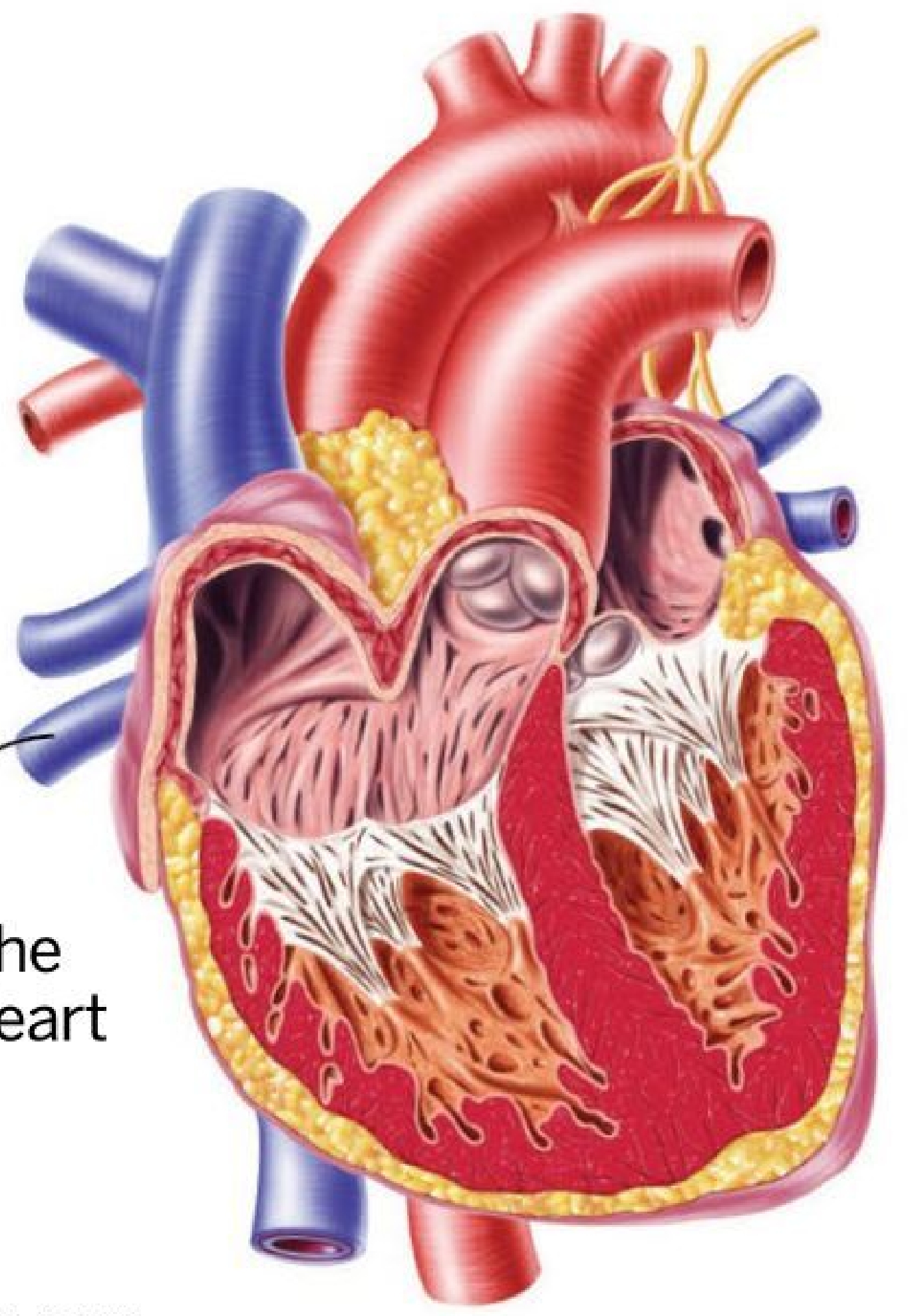
HOW IT WORKS

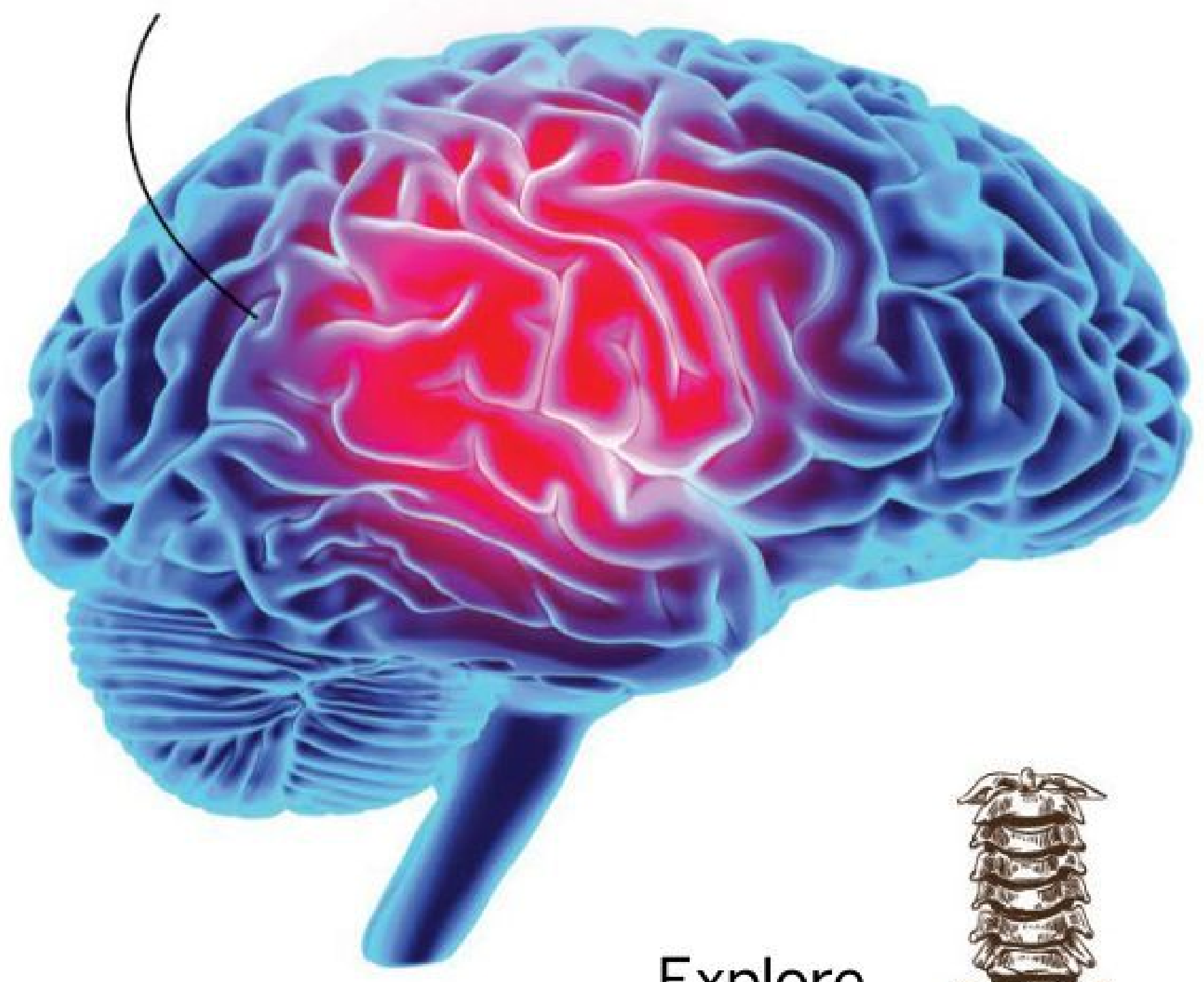
INSIDE THE HUMAN BODY

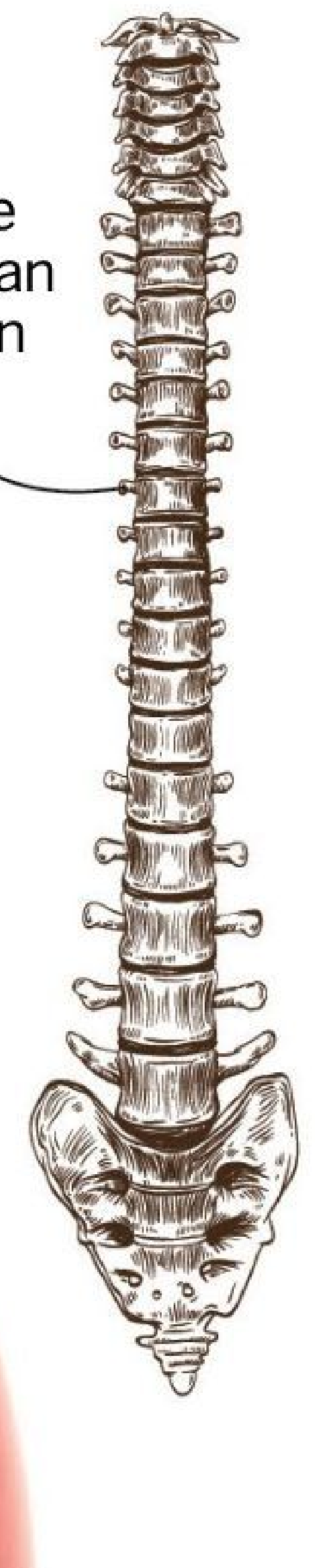
OVER 500 AMAZING FACTS

How our muscles work

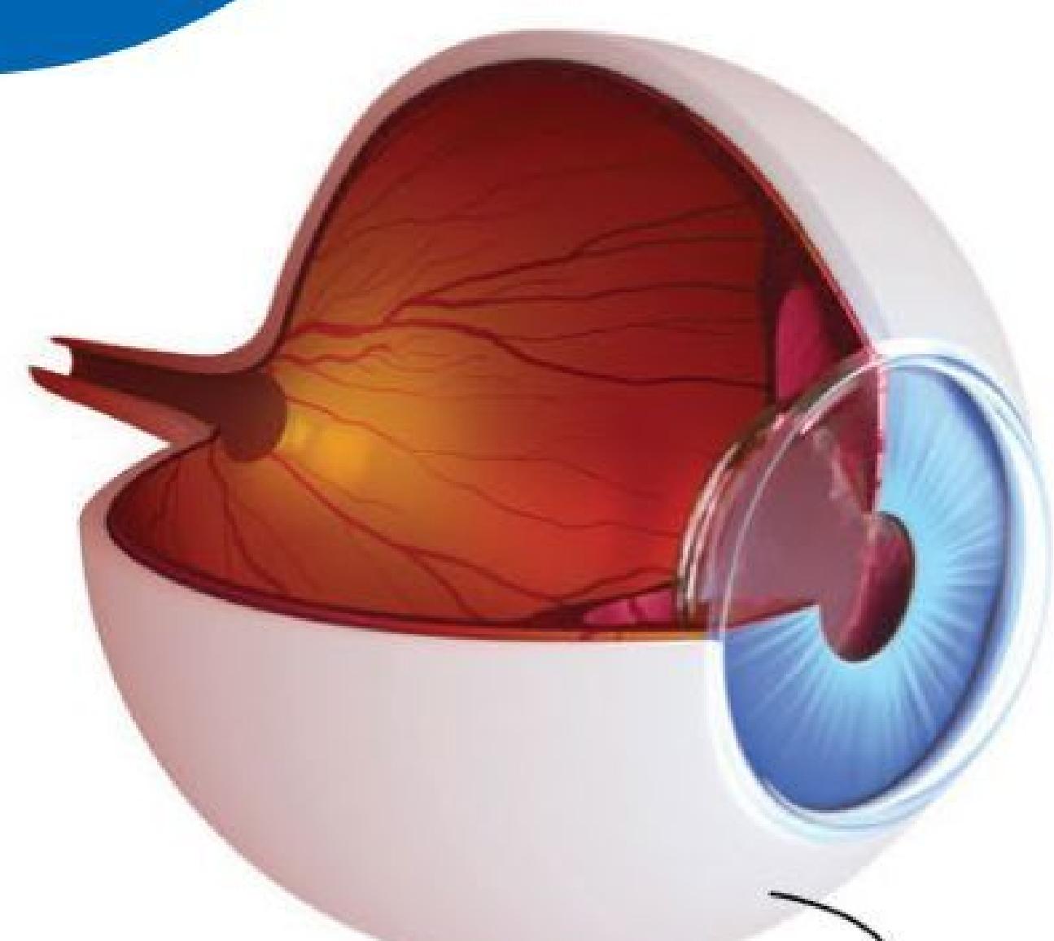

Explore vital organs

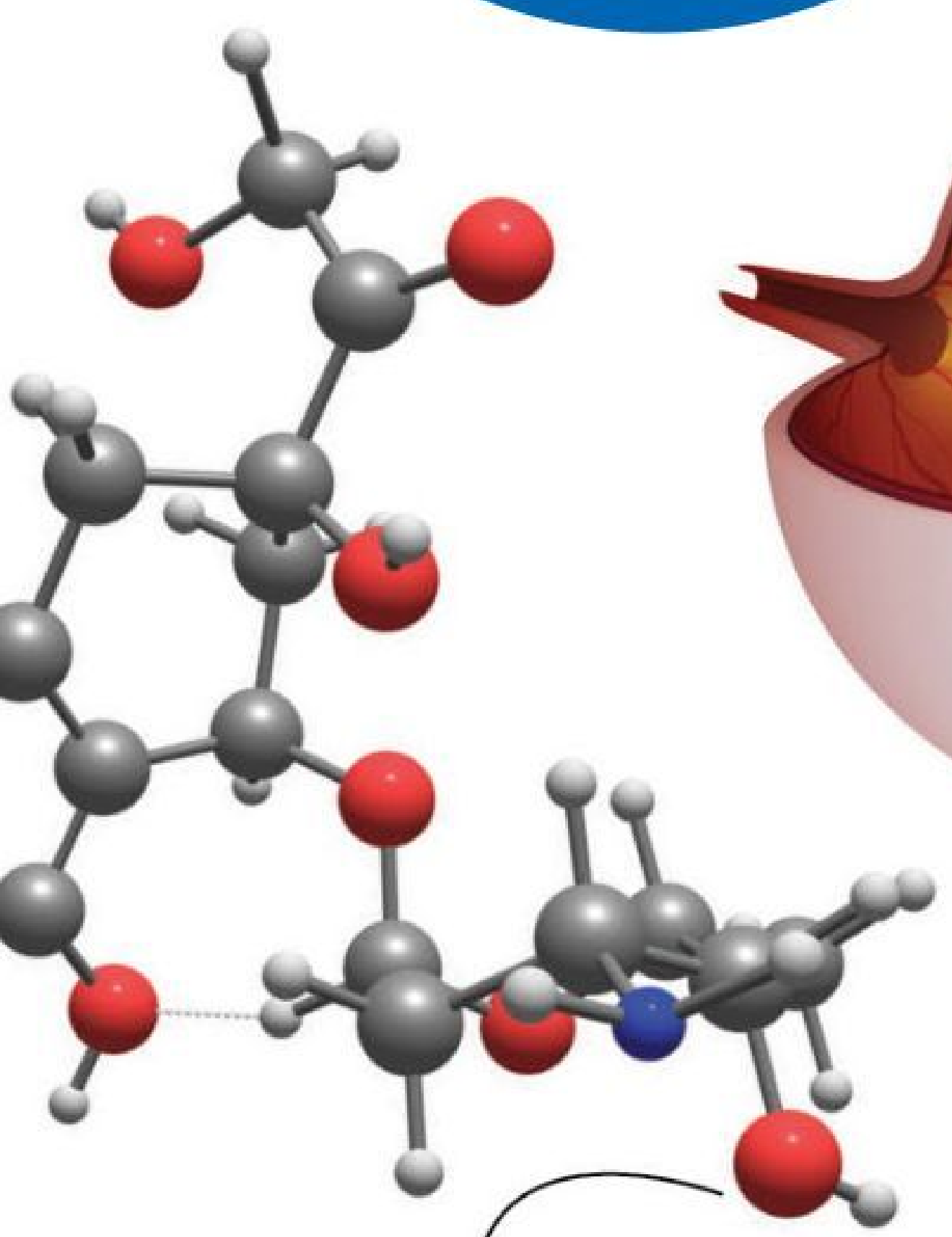

Inside the human heart

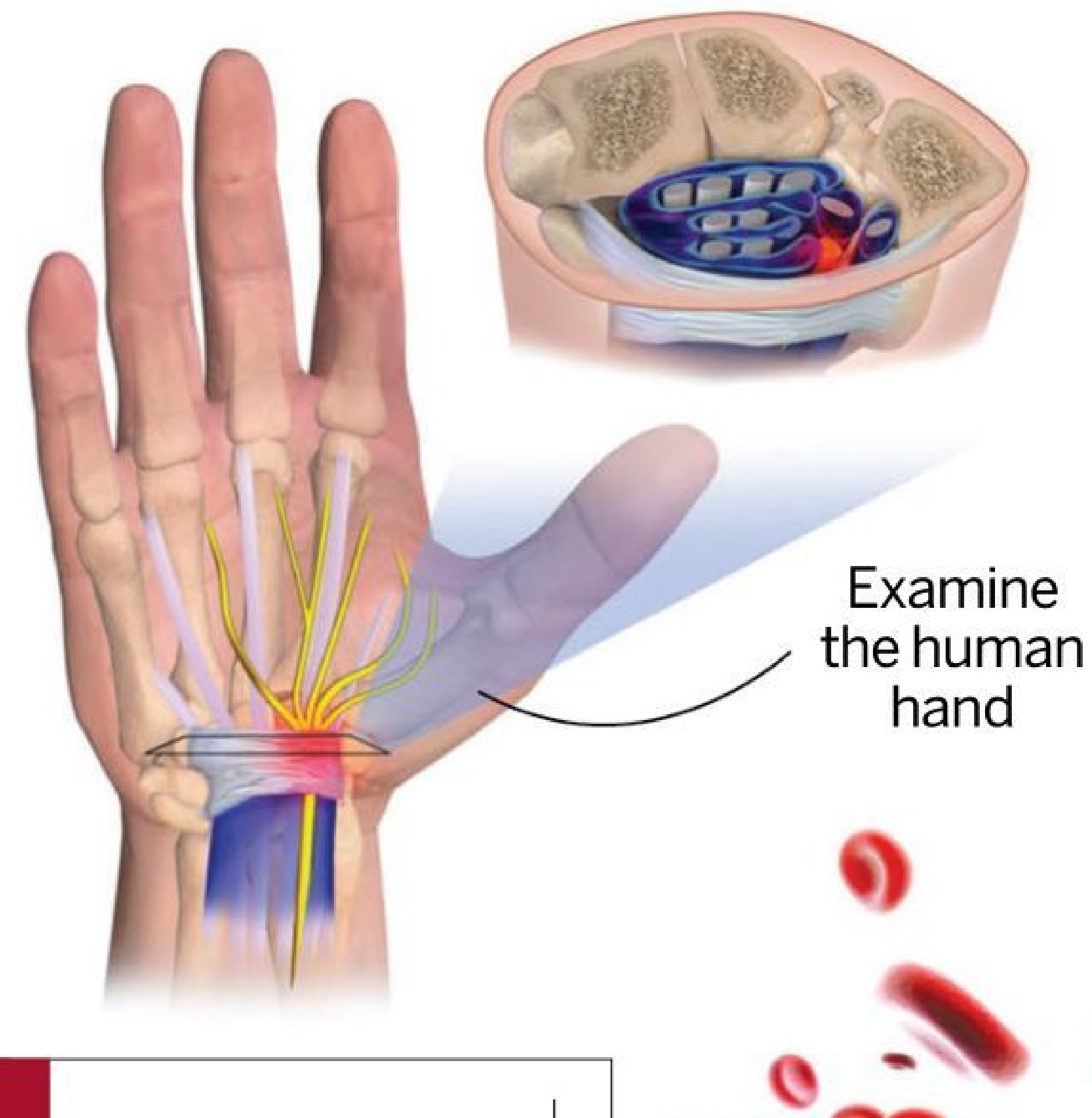

How your brain works

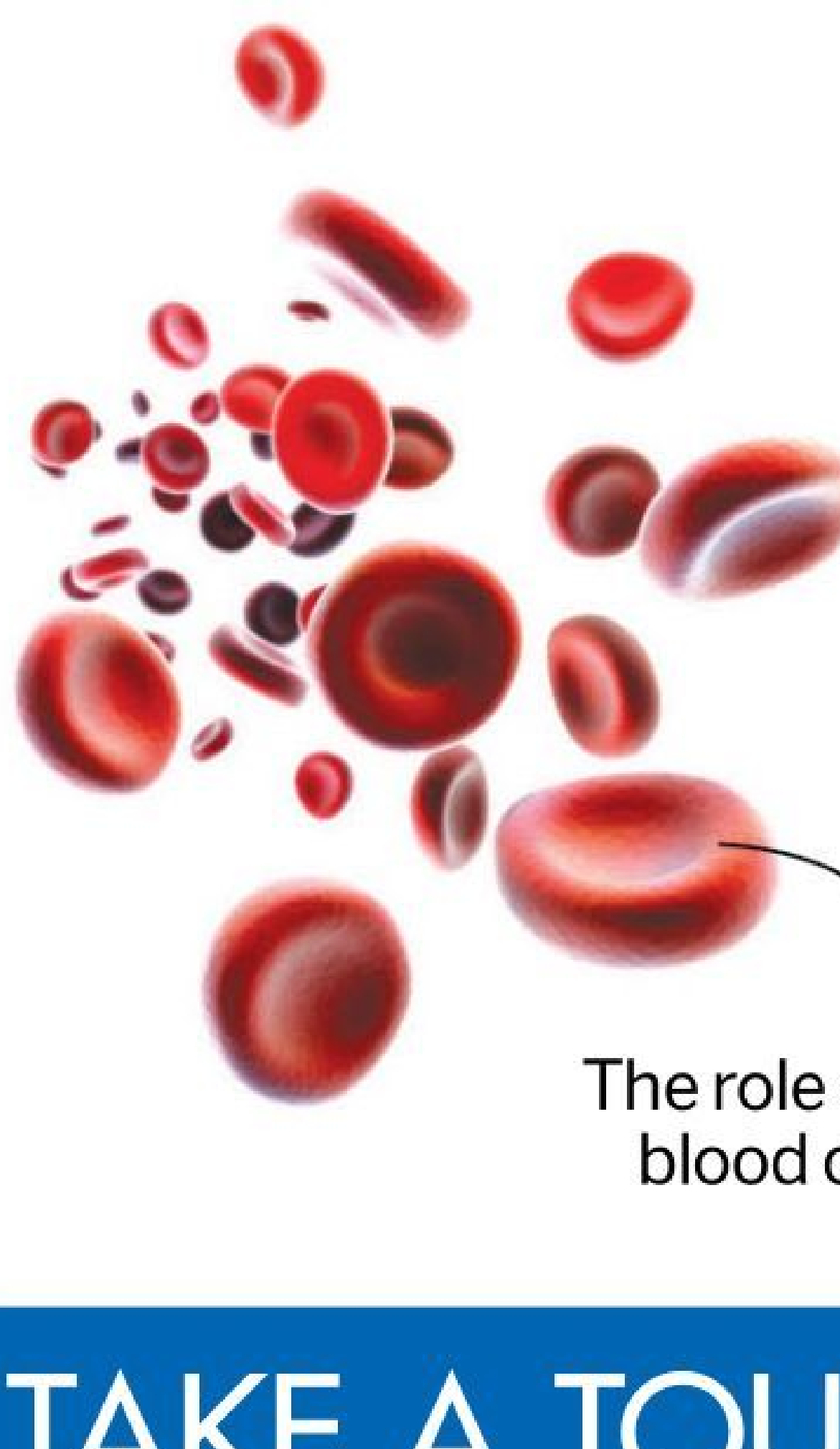

Explore the human skeleton

The body's essential organs


An in-depth look at the human eye


Fighting disease


Examine the human hand


The role of red blood cells

Digital Edition

FUTURE

FOURTH EDITION

TAKE A TOUR OF YOUR ANATOMY WITH OUR HEAD-TO-TOE GUIDE

Welcome to

HOW IT WORKS
INSIDE THE HUMAN BODY

Inside the Human Body takes you on a fascinating journey – starting at the very beginning, we explore how human beings came to exist and the ways in which our early ancestors evolved and adapted over hundreds of thousands of years. From here we get under the skin, taking an in-depth look at our most vital organs and body parts, from the complexity of the human brain to the structural support and strength offered by our muscles and skeleton. Working in tandem with modern medicine, our body does an amazing job of keeping us fit and healthy – we discover some of the body's most common complaints as well as investigating what the future of medicine may look like. We even tackle the body's weird and wonderful functions – exploring everything from why we laugh to the biology of a sneeze. This book will help you appreciate just how special you are and ensure you never take your body for granted again!

FUTURE

HOW IT WORKS

INSIDE THE HUMAN BODY

Future PLC Richmond House, 33 Richmond Hill,
Bournemouth, Dorset, BH2 6EZ

Editorial
Editor **Jacqueline Snowden**
Designer **Dani Dixon**
Editorial Director **Jon White**
Senior Art Editor **Andy Downes**

How It Works Editorial
Editor **Ben Biggs**
Senior Art Editor **Duncan Crook**

Photography
All copyrights and trademarks are recognised and respected

Advertising
Media packs are available on request
Commercial Director **Clare Dove**
clare.dove@futurenet.com

International
Head of Print Licensing **Rachel Shaw**
licensing@futurenet.com

Circulation
Head of Newstrade **Tim Mathers**

Production
Head of Production **Mark Constance**
Production Project Manager **Clare Scott**
Advertising Production Manager **Joanne Crosby**
Digital Editions Controller **Jason Hudson**
Production Managers **Keely Miller, Nola Cokely,**
Vivienne Calvert, Fran Twentyman

Management
Chief Content Officer **Aaron Asadi**
Commercial Finance Director **Dan Jotcham**
Head of Art & Design **Greg Whitaker**

Printed by William Gibbons, 26 Planetary Road,
Willenhall, West Midlands, WV13 3XT

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU
www.marketforce.co.uk Tel: 0203 787 9001

How It Works Inside The Human Body Fourth Edition
© 2019 Future Publishing Limited

We are committed to only using magazine paper which is derived from responsibly managed, certified forestry and chlorine-free manufacture. The paper in this magazine was sourced and produced from sustainable managed forests, conforming to strict environmental and socioeconomic standards. The manufacturing paper mill holds full FSC (Forest Stewardship Council) certification and accreditation

All contents © 2019 Future Publishing Limited or published under licence. All rights reserved. No part of this magazine may be used, stored, transmitted or reproduced in any way without the prior written permission of the publisher. Future Publishing Limited (company number 2008885) is registered in England and Wales. Registered office: Quay House, The Ambury, Bath BA1 1UA. All information contained in this publication is for information only and is, as far as we are aware, correct at the time of going to press. Future cannot accept any responsibility for errors or inaccuracies in such information. You are advised to contact manufacturers and retailers directly with regard to the price of products/services referred to in this publication. Apps and websites mentioned in this publication are not under our control. We are not responsible for their contents or any other changes or updates to them. This magazine is fully independent and not affiliated in any way with the companies mentioned herein.

FUTURE

Connectors.
Creators.
Experience
Makers.

Future plc is a public
company quoted on the
London Stock Exchange
(symbol: FUTR)
www.futureplc.com

Chief executive **Zillah Byng-Thorne**
Non-executive chairman **Richard Huntingford**
Chief financial officer **Penny Ladkin-Brand**

Tel +44 (0)1225 442 244

Part of the
HOW IT WORKS
bookazine series

ipso.
For press freedom
with responsibility

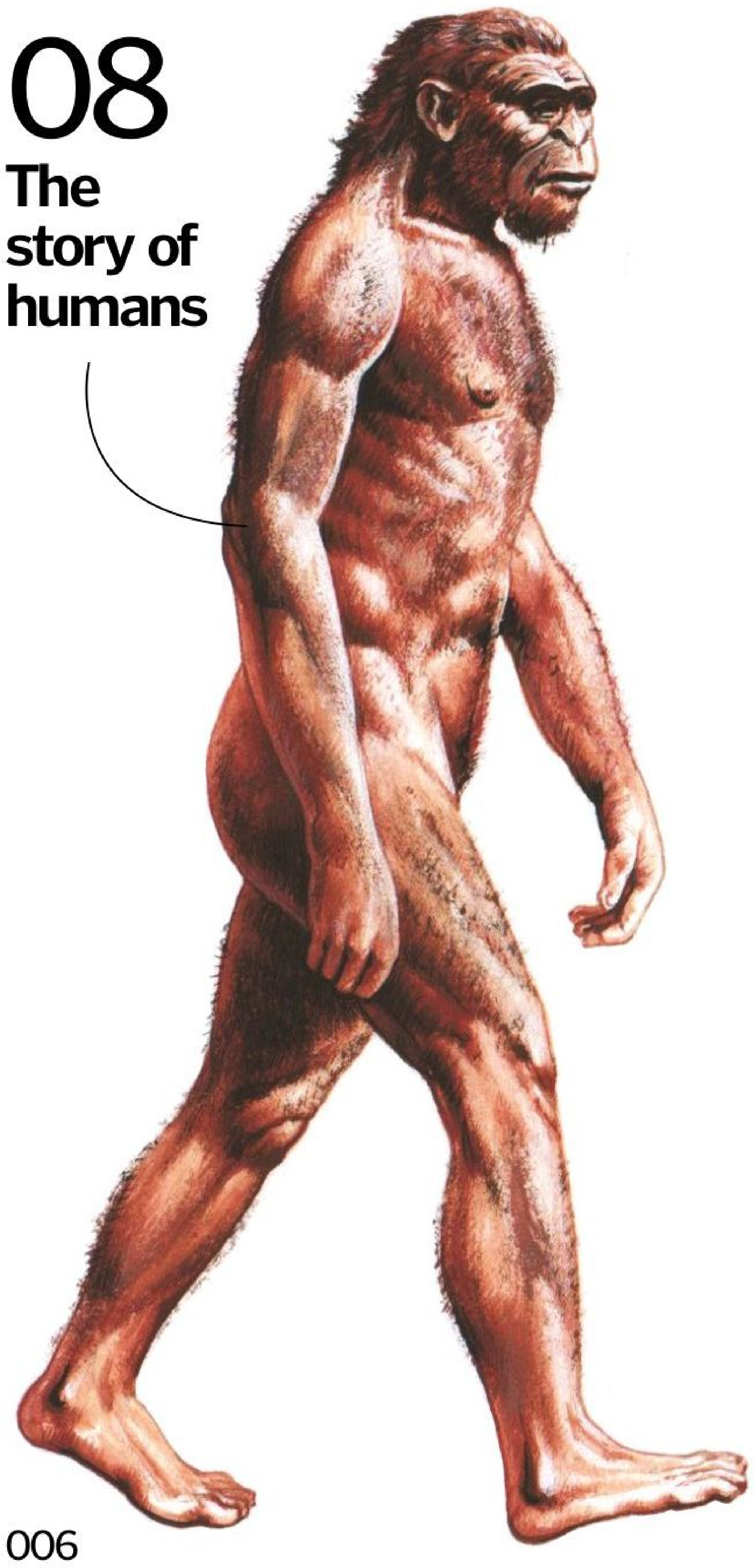
CONTENTS

THE STORY OF HUMANS

08 The story of humans

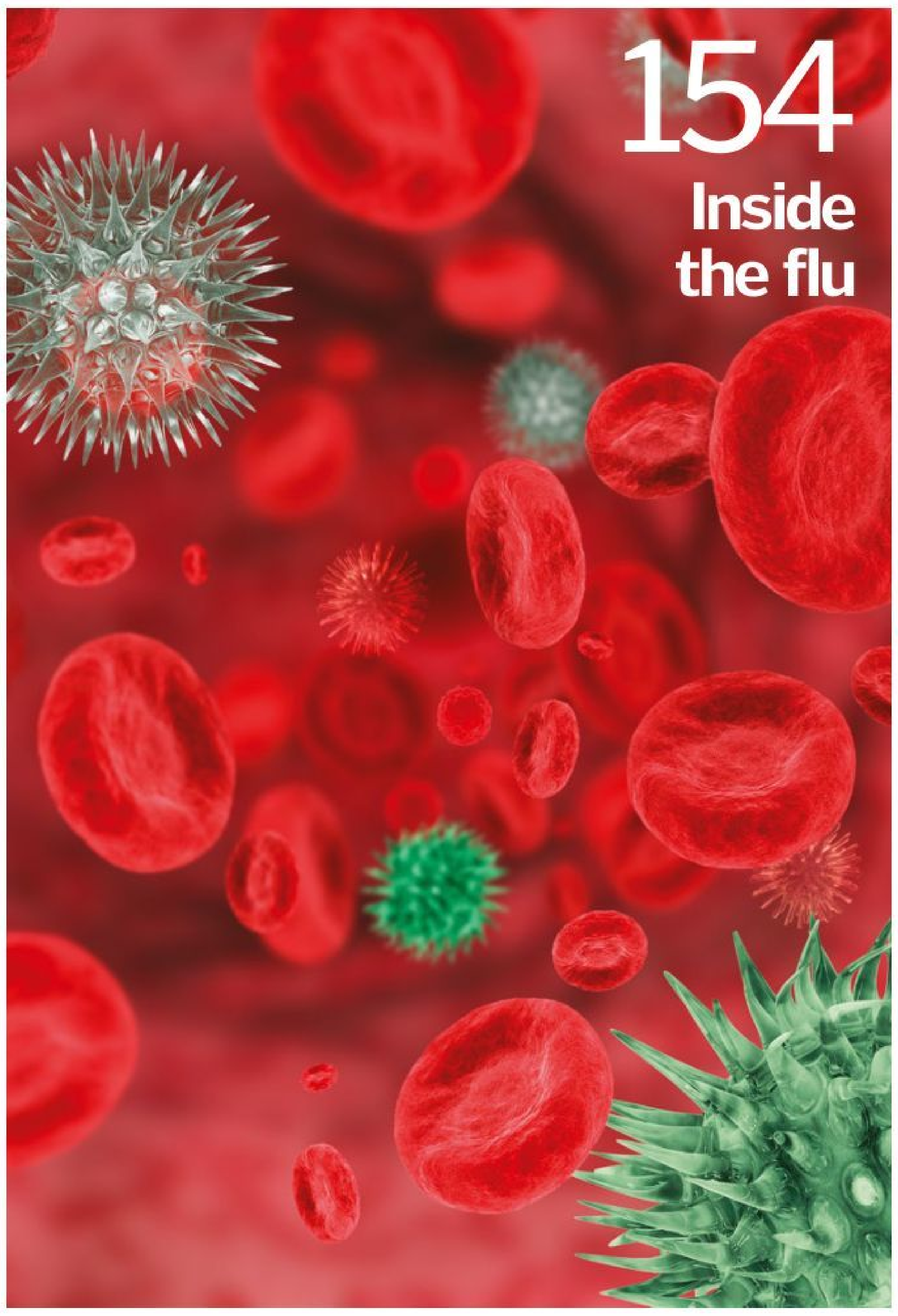
WHAT ARE WE MADE OF?

20 The human body
26 Your first year
32 Your amazing brain
40 Your skeleton
46 Inside a blood vessel
46 How cells work
47 The heart – a vital organ
48 Inside the liver and pancreas
50 What's inside your head
52 Inside the knee
53 What is thermoregulation?

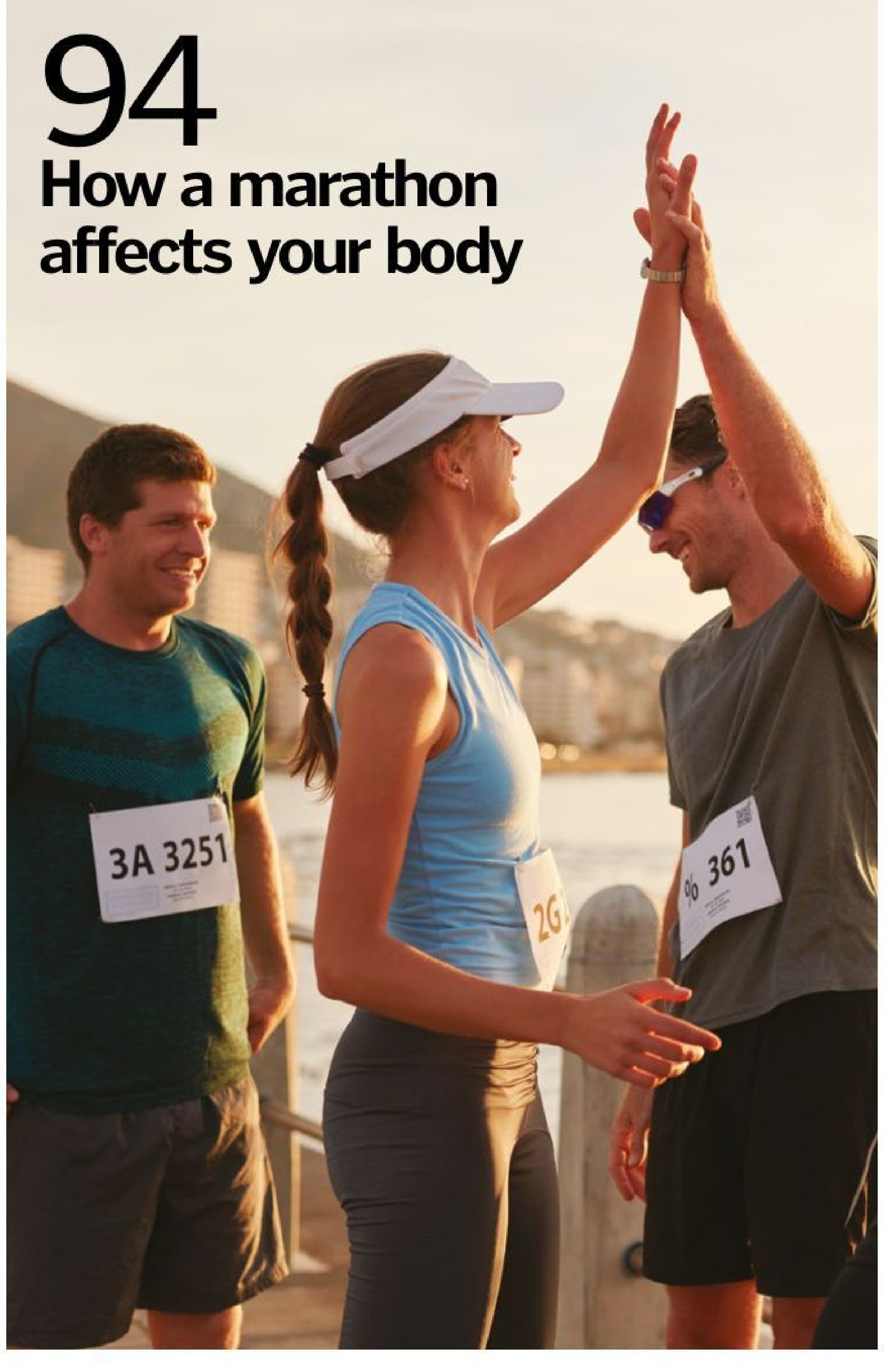


08
The story of humans

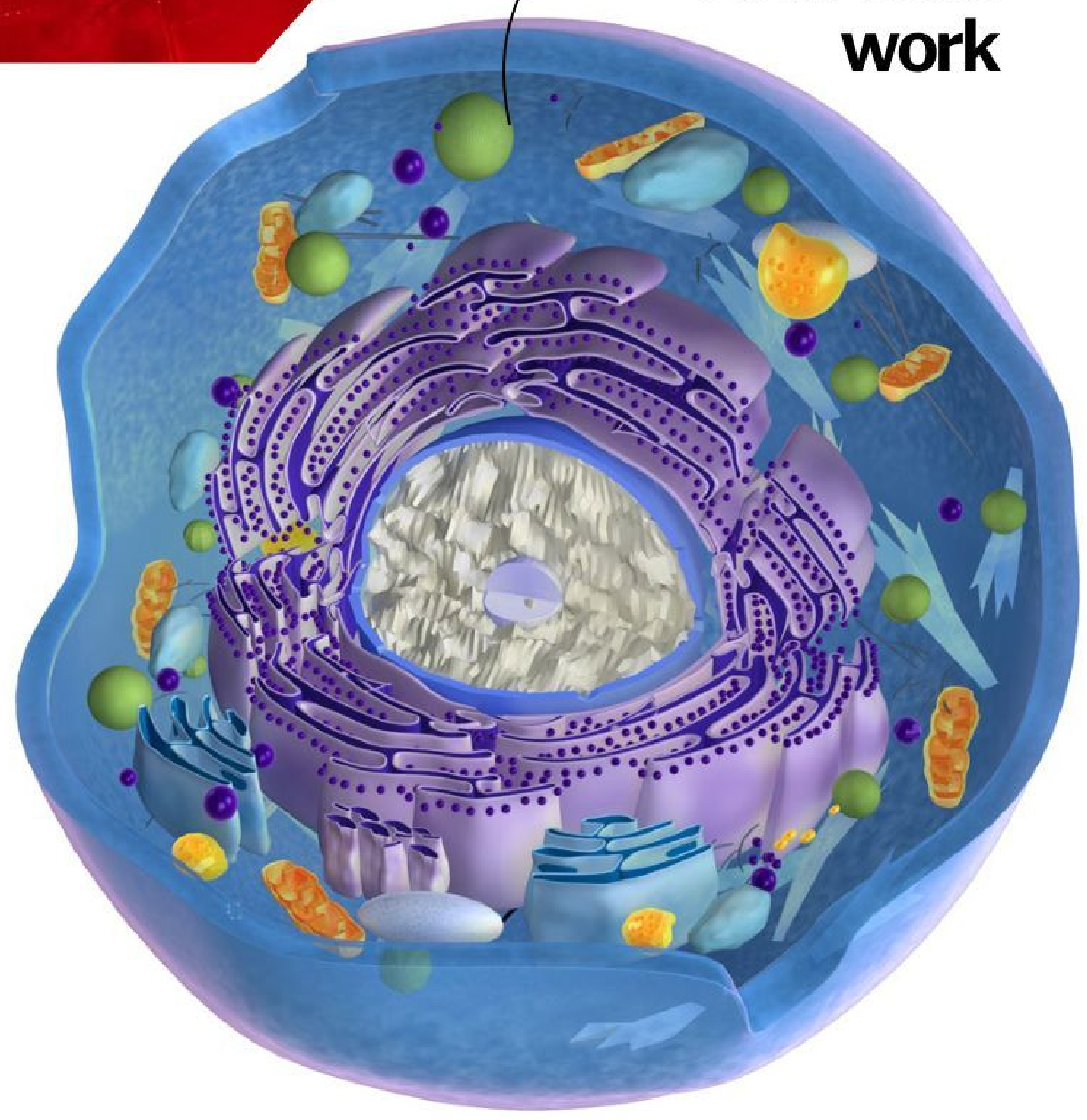
54 Muscle power
58 Science of vision
62 The retina
64 The human pelvis
66 The lymphatic system



154
Inside the flu



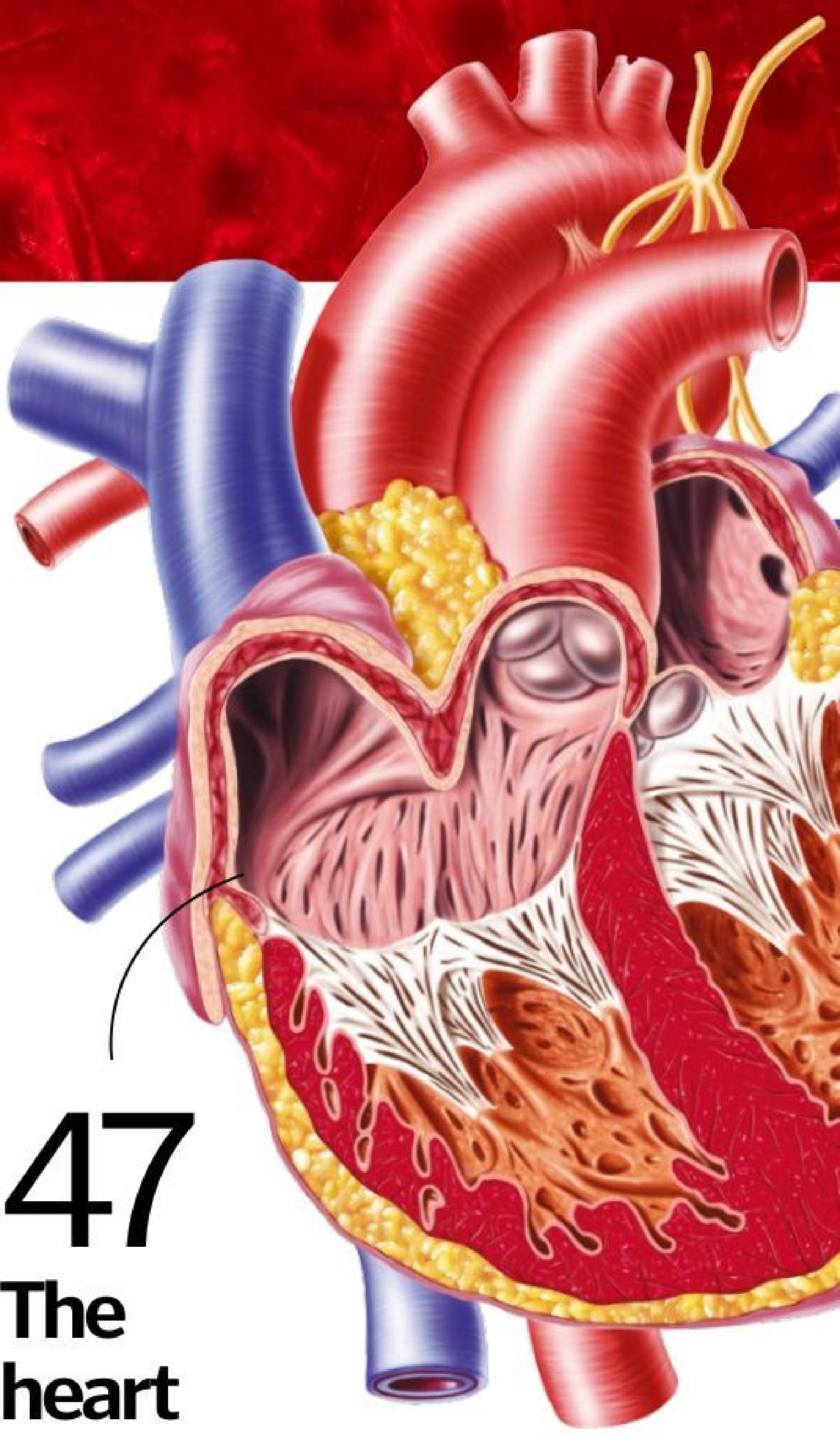
94
How a marathon affects your body



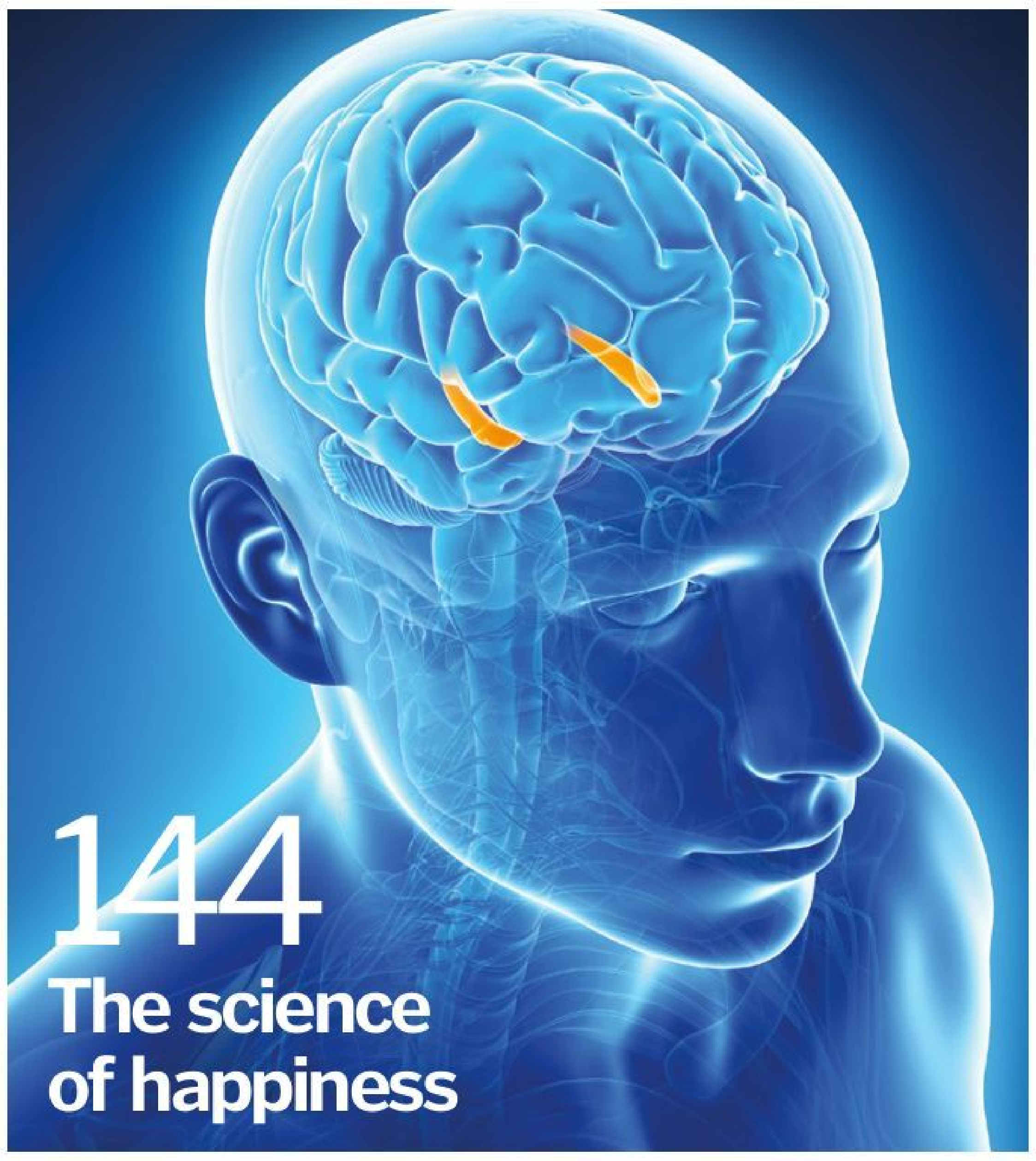
46
How cells work

HEALTH AND MEDICINE

70 Outbreak
76 Anatomy of an Olympic athlete
80 The truth about hair transplants
82 The antibiotic apocalypse
84 Why do we get fat?
84 Immunisation: how it keeps you healthy
85 How do we heal?
85 Placebos – do they work?
86 Kidney transplants
88 How cloning works
92 Anaesthetics
92 Strokes
93 Rheumatoid arthritis explained
93 Why is there no cure for the common cold?
94 How a marathon affects your body
96 The future of medicine
102 Why do we get headaches?
102 Asthma
103 Cramp explained
103 Blood clotting
104 How metabolism functions
105 How does the liver detoxify?
106 How do gastric bands work?
108 How skin grafts work
108 Is cholesterol bad for you?
109 Hypermobile joints
109 What is a fit?

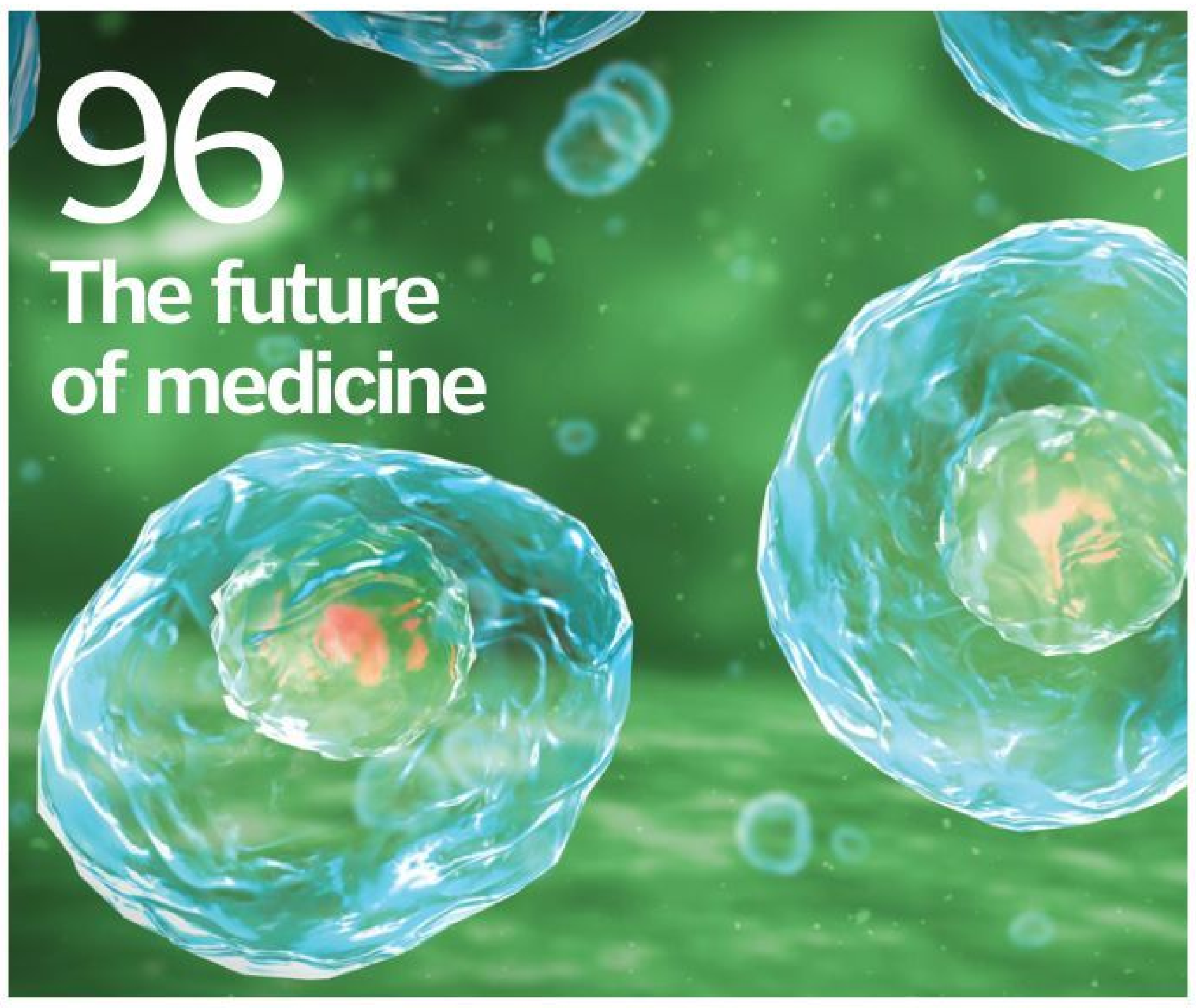


47 The heart

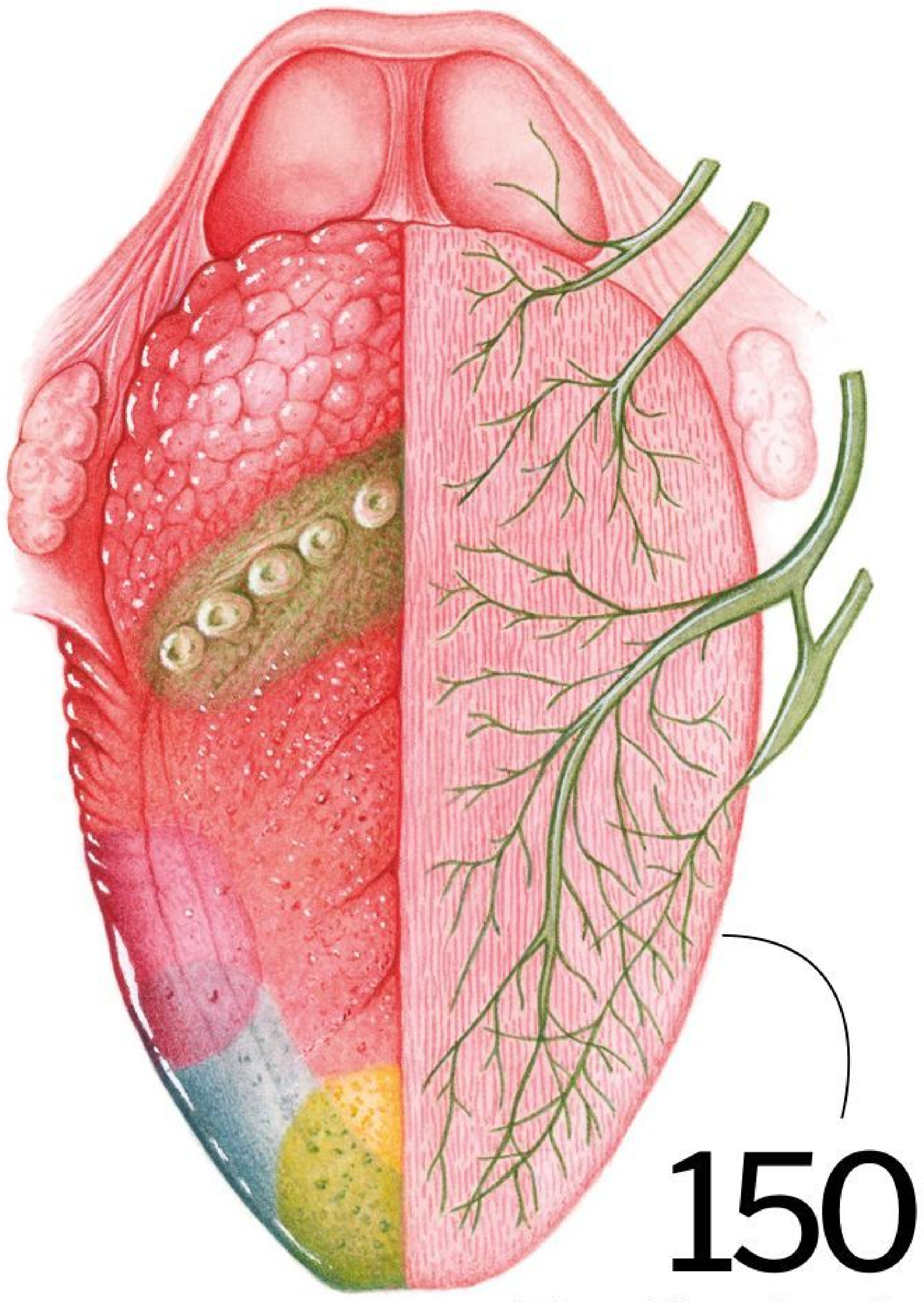


144 The science of happiness

110 Why do we get angry?
110 What are grommets?
111 Anaphylactic shock
112 Brain surgery
116 How hyperthermic surgery works
116 What are probiotic bacteria?
117 What are tonsils for?
118 Secrets of stem cells
120 Colour blindness
120 What causes stomach ulcers?
121 Understanding chickenpox
122 The war against superbugs
123 Curing deafness
124 Ebola virus
126 How enzymes keep you alive
126 Bacteria explained
127 How to check your pulse
127 Keeping hydrated
128 Understanding diabetes
130 Perfect posture
131 How corrective lenses work
132 Inside laser eye surgery



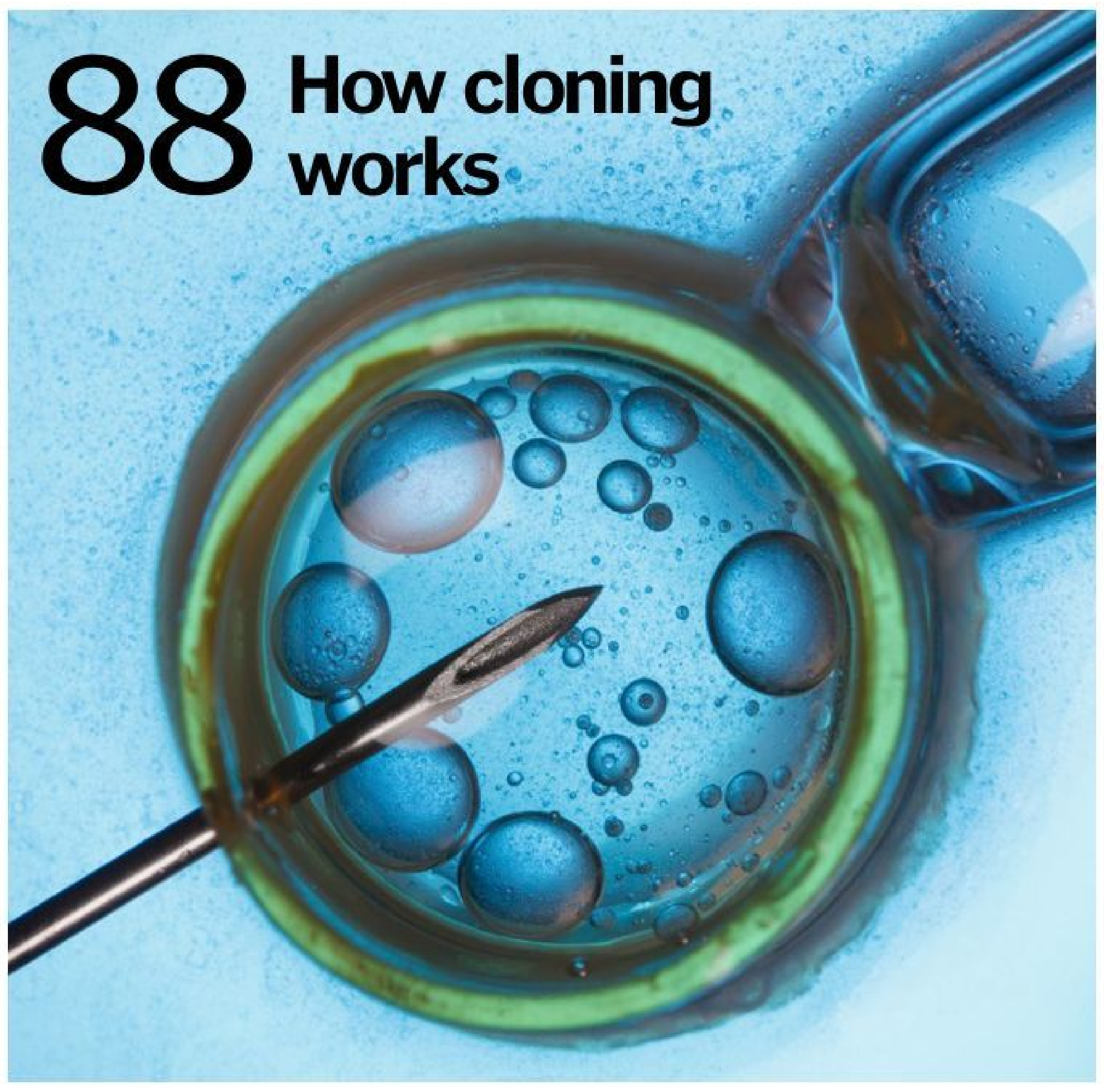
96 The future of medicine



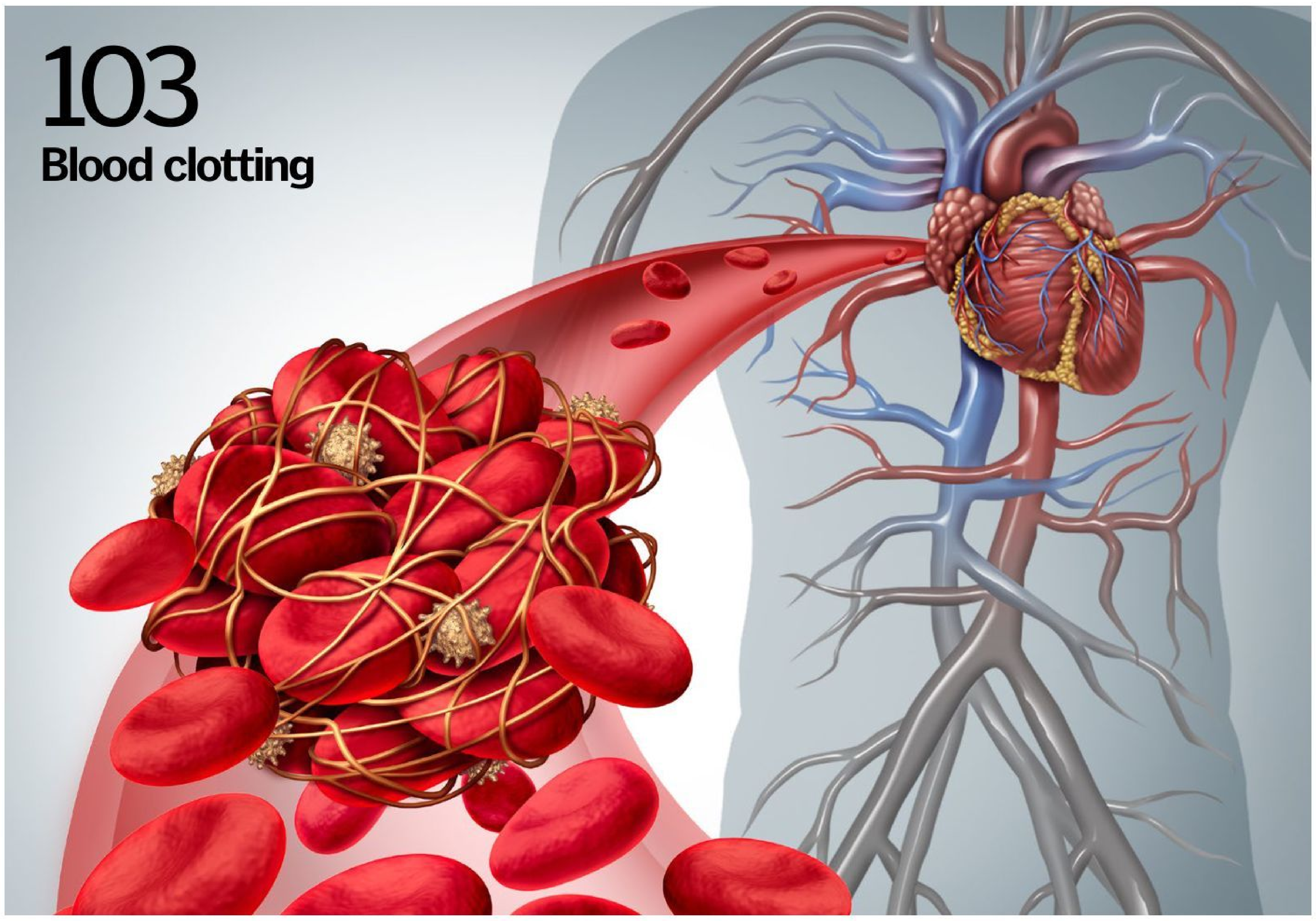
150 The five basic human tastes

PROCESSES AND BODILY FUNCTIONS

136 Food & your body
144 The science of happiness
148 The gut-brain axis
150 The five basic human tastes
151 Unravelling the mystery of DNA
152 Correcting heart rhythms
152 Carpal tunnel syndrome
153 What are pheromones?
153 Eczema explained
154 Inside the flu
156 How we swallow
156 Why do we get drunk?
157 The human tongue
157 How do we laugh?
158 What happens when you sneeze?
158 Knee-jerk reactions explained
159 How do we touch and feel?



88 How cloning works



103 Blood clotting

© Thinkstock; Dreamstime; DK images; Alamy

THE STORY OF HUMANS

HOW WE CROSSED CONTINENTS AND CONQUERED THE PLANET

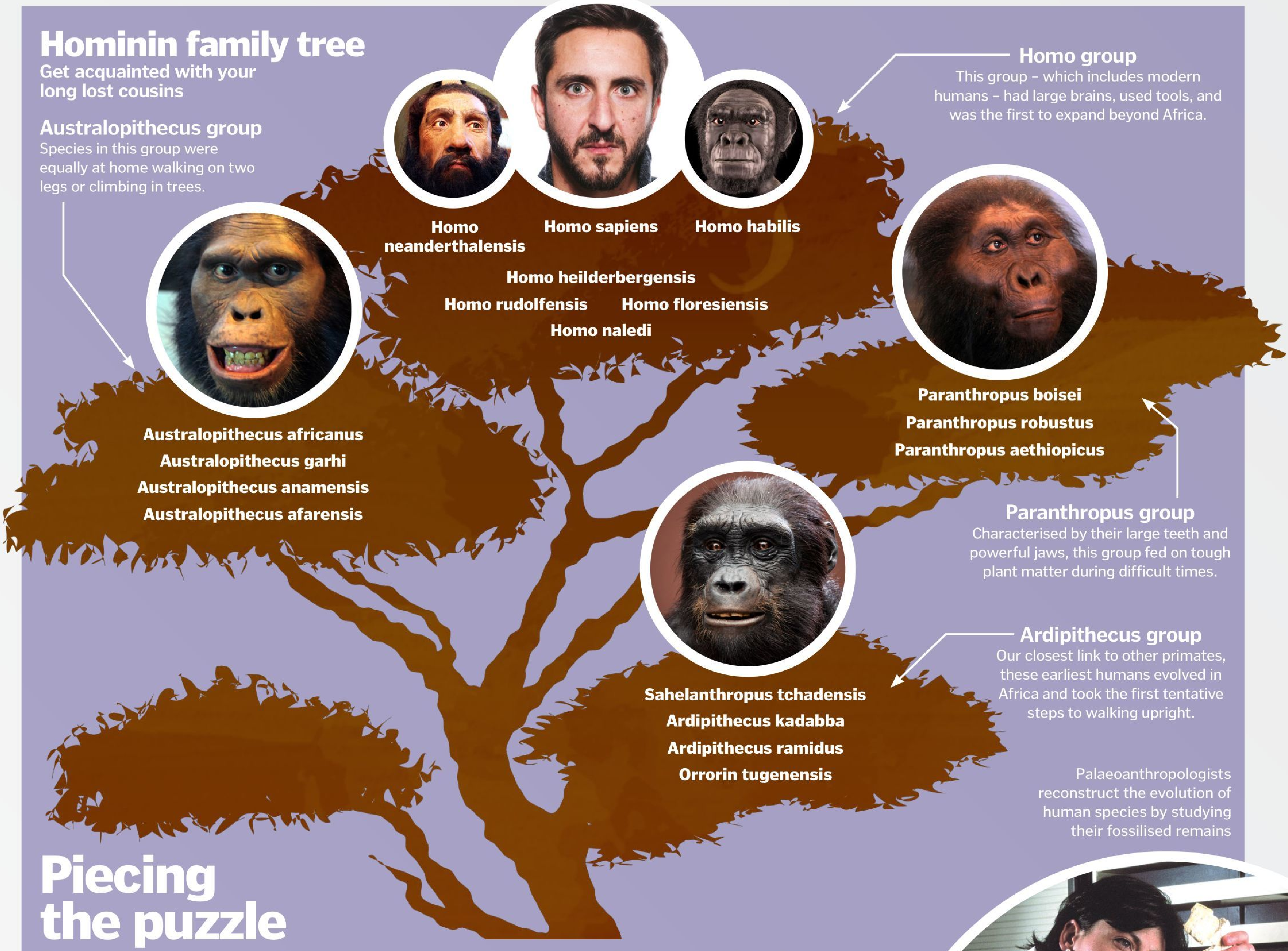
DID YOU KNOW? *The earliest human footprints found outside of Africa were discovered in Norfolk, England*

In the iconic *March of Progress* illustration, human evolution is depicted as a single flowing process that begins with apes and ends with our modern selves. But in truth, our evolutionary past is a messier affair, involving an assortment of ancestors treading a multitude of paths that split, stumble and intersect in ambiguous ways.

When we draw family trees, each end branch represents a distinct species – a grouping of individuals that are genetically similar enough to interbreed. New species evolve through the process of natural selection: environmental pressures favour some traits over others, which causes populations to gradually adapt or diverge in order to have a better chance of surviving.

Despite a fragmentary fossil record, scholars have traced the evolution of hominins – that is, the group of species including modern humans and our ancient bipedal ancestors – back more than six million years. But field scientists are still uncovering 'new' extinct hominins, meaning that our understanding of human evolution is itself constantly evolving.

While we know that modern humans and chimpanzees diverged from a common ancestor between six and eight million years ago, scientists are still striving to find the earliest hominin and pin down the moment the two lineages split. Above all, they seek to answer the most fundamental question in human evolution: what sequence of events and adaptations occurred to transform apes into humans?



Hominin family tree

Get acquainted with your long lost cousins

Australopithecus group

Species in this group were equally at home walking on two legs or climbing in trees.

Homo neanderthalensis

Homo sapiens

Homo habilis

Homo heilderbergensis

Homo rudolfensis

Homo floresiensis

Homo naledi

Homo group

This group – which includes modern humans – had large brains, used tools, and was the first to expand beyond Africa.

Australopithecus africanus

Australopithecus garhi

Australopithecus anamensis

Australopithecus afarensis

Paranthropus boisei

Paranthropus robustus

Paranthropus aethiopicus

Paranthropus group

Characterised by their large teeth and powerful jaws, this group fed on tough plant matter during difficult times.

Sahelanthropus tchadensis

Ardipithecus kadabba

Ardipithecus ramidus

Orrorin tugenensis

Ardipithecus group

Our closest link to other primates, these earliest humans evolved in Africa and took the first tentative steps to walking upright.

Piecing the puzzle

Palaeoanthropologists are scientists who peer into our evolutionary past. As they try to piece together our family tree, their most important clues come from fossils – physical evidence of ancient hominins, like bones and teeth, which help to classify different species.

In order to reconstruct how species evolved, it is crucial to know how old these fossils are. However, the commonly used method of radiocarbon dating can only be used on specimens younger than 40,000 years old.

Instead, experts look at materials in close proximity to the fossils, such as the layers of rock they were discovered in. Careful study of local geology combined with chemical analysis allows fossils and artefacts within the layers to be dated.

In the last decade, DNA sequencing has revolutionised this field. Because genetic mutations happen at predictable rates and are passed from parent to child, fragments of ancient DNA can be compared to our own to reveal secrets about our ancestors' biology and behaviour.

Palaeoanthropologists reconstruct the evolution of human species by studying their fossilised remains

The Homo genus

What set our closest relatives apart from earlier human species?

Every human on the planet today is a member of one single species: Homo sapiens. Together with our extinct ancestors and closest relatives, we are part of the broader genus of Homo, whose members all share unmistakably human traits.

The Homo genus emerged somewhere around three million years ago in Africa, when the region was home to at least 11 species of hominin. The oldest Homo fossil – dated at 2.8 million years old – was a member of the species Homo habilis. Its name means 'handy man', as it is believed to be the first hominin that used stone tools. Although it retained many of the ape-like body features of earlier Australopithecus, its brain was much larger.

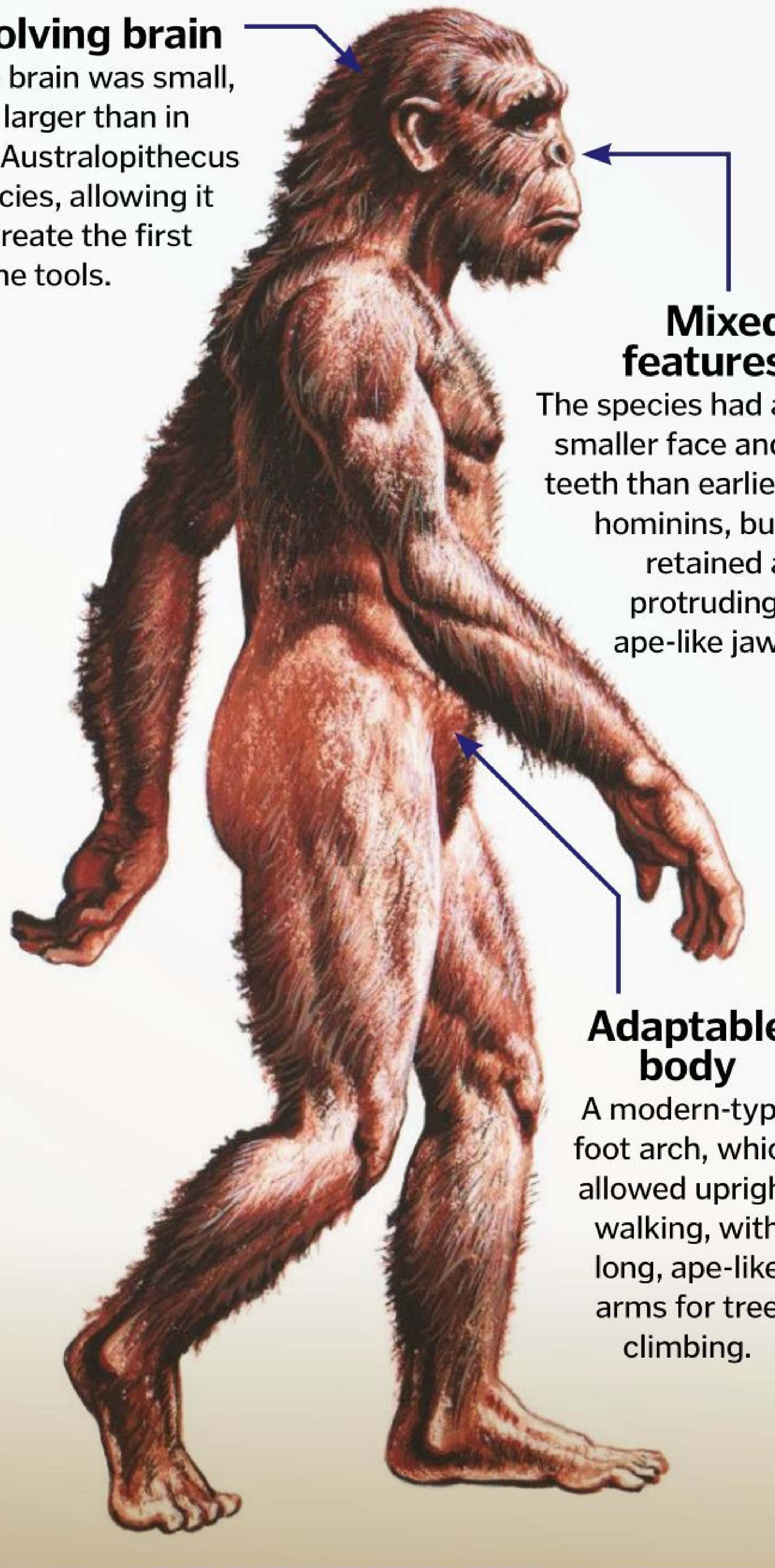
Tool use and brain size are two of the defining characteristics of the Homo genus. The third is an upright skeleton that enables walking on two feet. Together these changes gave an evolutionary edge in exploiting the environment, solving problems, and journeying over long distances.

Our own species is thought to have evolved 200,000 years ago from the strong, athletic Homo heidelbergensis. They in turn evolved from Homo erectus – one of the most successful hominins in history, surviving for two million years.

For a long time, scientists have argued over whether H. sapiens evolved within Africa before spreading around the world (the Out of Africa hypothesis) or evolved simultaneously in many locations (the multiregional hypothesis). Recent studies of DNA suggest we descend from a single population living 150,000 years ago, which heavily supports the Out of Africa theory.

Homo species identifier

Discover the characteristic features of some of the most prominent members of the genus



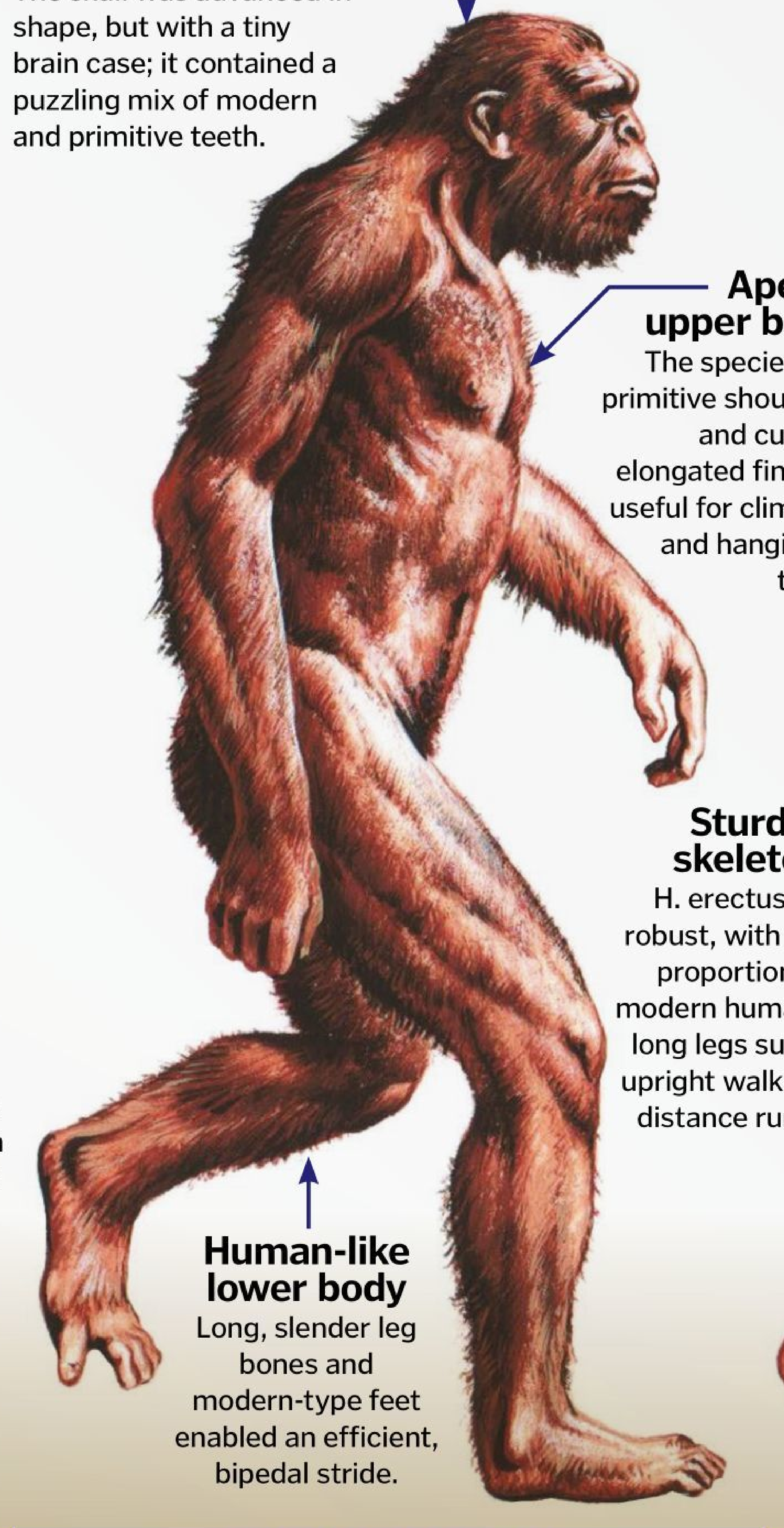
Evolving brain
The brain was small, but larger than in the Australopithecus species, allowing it to create the first stone tools.

Mixed features
The species had a smaller face and teeth than earlier hominins, but retained a protruding, ape-like jaw.

Adaptable body
A modern-type foot arch, which allowed upright walking, with long, ape-like arms for tree climbing.

HOMO HABILIS

Height: **1.1-1.2m** Weight: **30-36kg**
Average brain size: **610cm³**



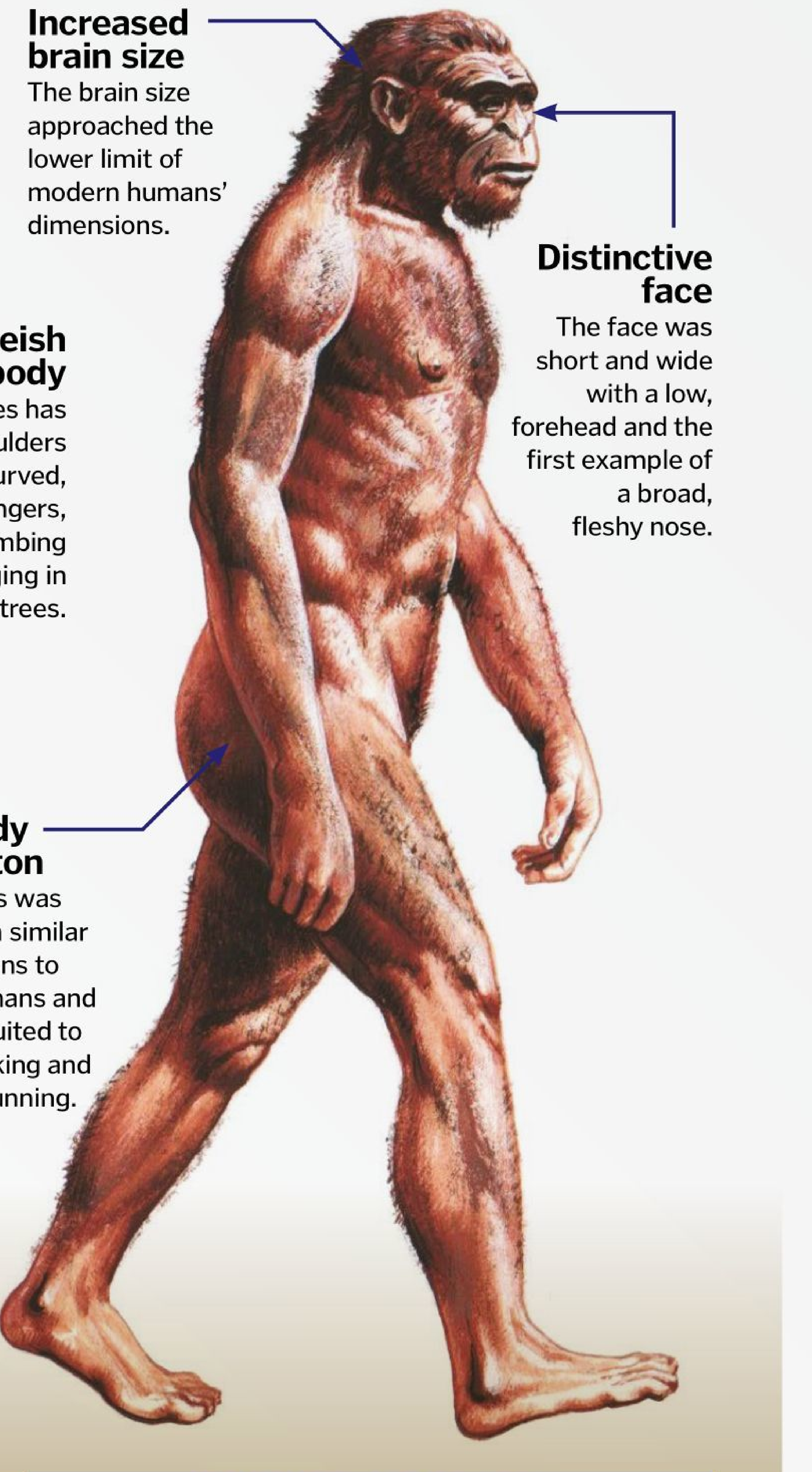
Petite skull
The skull was advanced in shape, but with a tiny brain case; it contained a puzzling mix of modern and primitive teeth.

Apeish upper body
The species has primitive shoulders and curved, elongated fingers, useful for climbing and hanging in trees.

Human-like lower body
Long, slender leg bones and modern-type feet enabled an efficient, bipedal stride.

HOMO NALEDI

Height: **Approx 1.5m** Weight: **Approx 45kg**
Average brain size: **560 cm³**



Increased brain size
The brain size approached the lower limit of modern humans' dimensions.

Distinctive face
The face was short and wide with a low, forehead and the first example of a broad, fleshy nose.

Sturdy skeleton
H. erectus was robust, with similar proportions to modern humans and long legs suited to upright walking and distance running.

HOMO ERECTUS

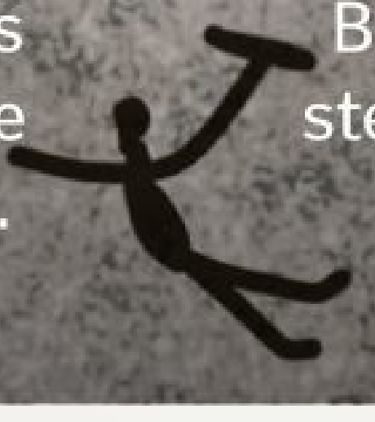
Height: **1.45-1.8m** Weight: **40-68kg**
Average brain size: **1,050cm³**

HUMAN HISTORY TIMELINE

6-8 MILLION YEARS AGO
Divergence of human and chimpanzee lineages from the last common ancestor.

6-7 MILLION YEARS AGO
Sahelanthropus tchadensis develops small canines, distinguishing it from apes.

6 MILLION YEARS AGO
Sahelanthropus walks upright, becoming the first bipedal hominin.



2-6 MILLION YEARS AGO
Brain size undergoes a slow, steady increase as bipedalism and tool use proliferate.

DID YOU KNOW? *The term Homo sapiens comes from Latin and means 'wise man'*

Did humans and Neanderthals interbreed?

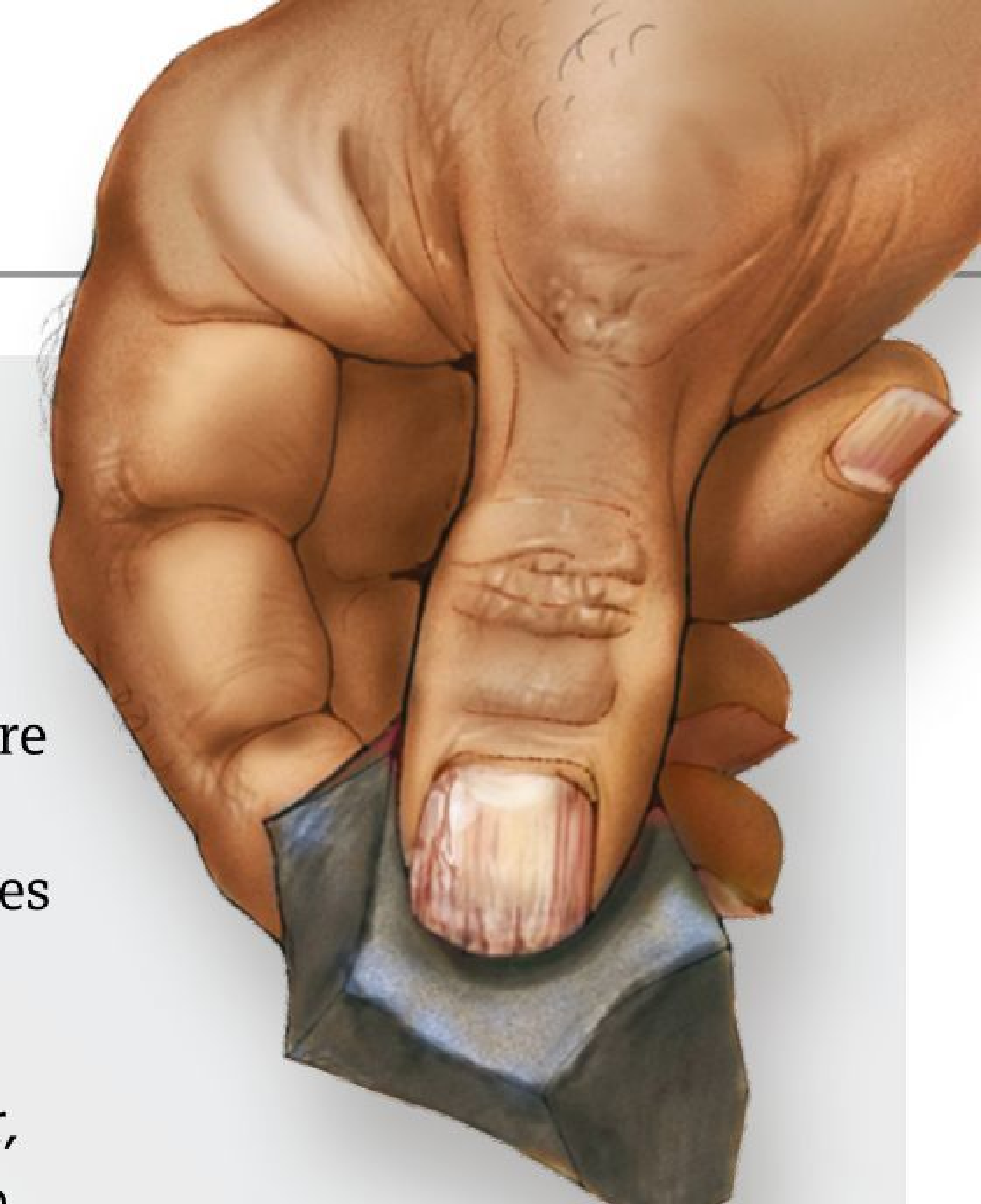
In 2010, scientists announced a startling new twist in the human evolution story. Recently extracted fragments of Homo neanderthalensis DNA showed that 50,000 to 60,000 years ago – when they overlapped with modern humans in the Levant as they were flowing towards Eurasia – the two species occasionally interbred. In fact, the genome of everyone alive today who is not of African descent contains somewhere between one and four per cent Neanderthal DNA.

Neanderthals are our closest cousins, having also evolved from H. heidelbergensis. Although it is sometimes possible for two genetically similar species to have offspring together, some scientists were initially sceptical. They argued that the shared DNA came from the two species sharing a common – as yet unknown – ancestor. Today, leading experts say new, more detailed analyses have finally laid the question to rest; some of us are just a little bit Neanderthal!

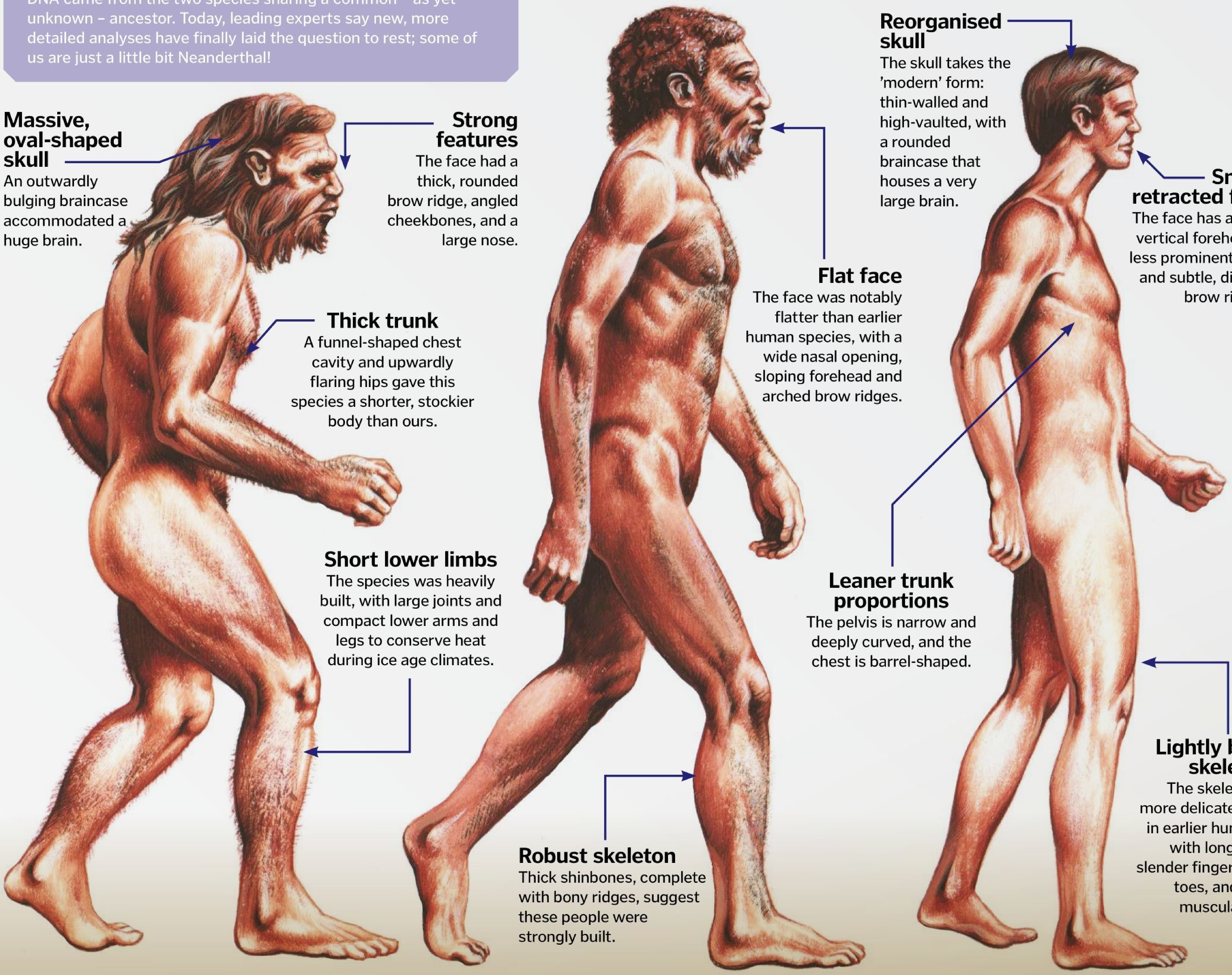
Opposable thumbs

The grasping hands of our primate ancestors evolved as an adaptation to life in the trees. Opposable thumbs – which are able to move around and touch the other fingers – and flat fingertip pads both help tree-dwellers to grab on to branches as well as hold and manipulate small objects.

Our modern thumb has changed little since the last common ancestor of humans and chimpanzees. It is longer, compared to finger length, than any other primate's thumb, giving both strength and precision. This helped our ancestors gather a wide variety of foods and eventually develop tools.



An opposable thumb enables the hand to grip with strength and dexterity



Massive, oval-shaped skull
An outwardly bulging braincase accommodated a huge brain.

Strong features
The face had a thick, rounded brow ridge, angled cheekbones, and a large nose.

Thick trunk
A funnel-shaped chest cavity and upwardly flaring hips gave this species a shorter, stockier body than ours.

Short lower limbs
The species was heavily built, with large joints and compact lower arms and legs to conserve heat during ice age climates.

Flat face
The face was notably flatter than earlier human species, with a wide nasal opening, sloping forehead and arched brow ridges.

Robust skeleton
Thick shinbones, complete with bony ridges, suggest these people were strongly built.

Reorganised skull
The skull takes the 'modern' form: thin-walled and high-vaulted, with a rounded braincase that houses a very large brain.

Small, retracted face
The face has a high, vertical forehead, a less prominent nose and subtle, divided brow ridges.

Leaner trunk proportions
The pelvis is narrow and deeply curved, and the chest is barrel-shaped.

Lightly built skeleton
The skeleton is more delicate than in earlier humans, with long legs, slender fingers and toes, and lean musculature.

HOMO NEANDERTHALENSIS

Height: **1.5-1.6m** Weight: **54-65kg**
Average brain size: **1,420 cm^3**

HOMO HEIDELBERGENSIS

Height: **1.6-1.8m** Weight: **51-62kg**
Average brain size: **1,270cm^3**

HOMO SAPIENS

Height: **1.6-1.8m** Weight: **62-78kg**
Average brain size: **1,350 cm^3**

4 MILLION YEARS AGO
Human ancestors are mostly bipedal, but are also still comfortable in trees.

3-3.5 MILLION YEARS AGO
Many species of Australopithecus thrive within Africa.

3.3 MILLION YEARS AGO
Infant growth rate slows and starts to resemble that of modern humans.

2.8 MILLION YEARS AGO
The earliest known member of the Homo genus – Homo habilis – emerges in Africa.

Tools and development

How physical adaptations and new skills helped advance human species

Four major development trends separate humans from apes: terrestrialism, which is the move from tree-dwelling to ground living; bipedalism, the shift from moving on all fours to walking upright on two legs; encephalisation, which is an increase in brain-to-body mass ratio; and civilisation – a catch-all that includes social organisation, technological thought, communication and culture.

Separating cause from effect in these areas is tricky and experts disagree over the order in which they unfolded. But climate science offers some of the most compelling evidence for where it all started.

Beginning around ten million years ago, Africa's climate altered profoundly from lush tropical forests to sparse, open grassland. As food sources became more thinly distributed, walking on two legs would have enabled early humans to forage over long distances and even carry provisions for later. With reduced vegetation cover, standing upright would also have helped keep their bodies cool by reducing the exposed skin surface area, and moving more of the body up into the breeze and away from the hot earth.

Picking apart the other developments is more challenging. In particular, it isn't clear what spurred the expansion of the human brain. Mental skills perhaps became more important as a result of increasingly complex social interactions or the demanding technological thought required to produce stone tools. On the other hand, brain enlargement may only have been triggered once easily digestible, energy-dense food was available on a regular basis – in other words, after humans had figured out how to procure and cook meat. Homo species' digestive tracts then became shorter, freeing up energy for larger brains and bodies.

Tool-making became more systematic and the products more uniform; experts speculate that these increasingly ordered cognitive processes eventually led to organised language, symbolic thought and creative expression.

> *"Humans have been using tools for at least three million years"*

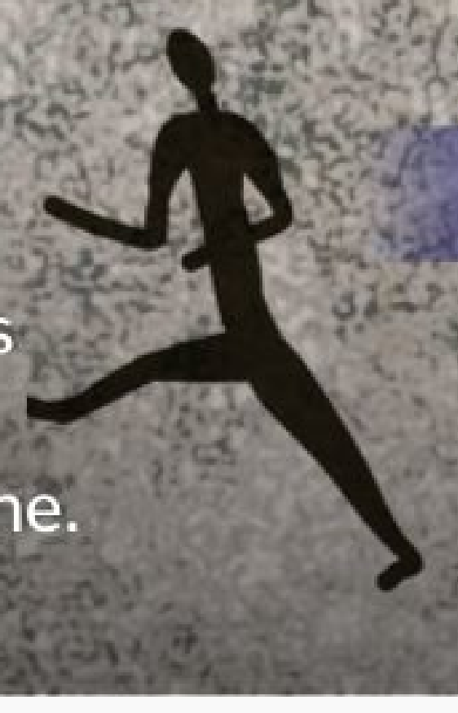
Lethal weapons

Traces of glue – perhaps tree sap or tar – found on Neanderthal-crafted stone points suggest that they were once attached to wooden shafts. Lashed in place with plant fibres, sinew, or leather, these would have made handsome spears, allowing Neanderthals to hunt larger prey from a safe distance, perhaps in cooperative groups.

Thrusting spears gave Neanderthals the new predatory edge to hunt large prey

2.6 MILLION YEARS AGO
The dawn of technology: hammerstones and cores are used to produce sharp flakes.

2.6 MILLION YEARS AGO
Stone tools give access to new foods, including meat from large animals.



2.5 MILLION YEARS AGO
Australopithecus africanus develops modern, shock-absorbing curve in lower spine.

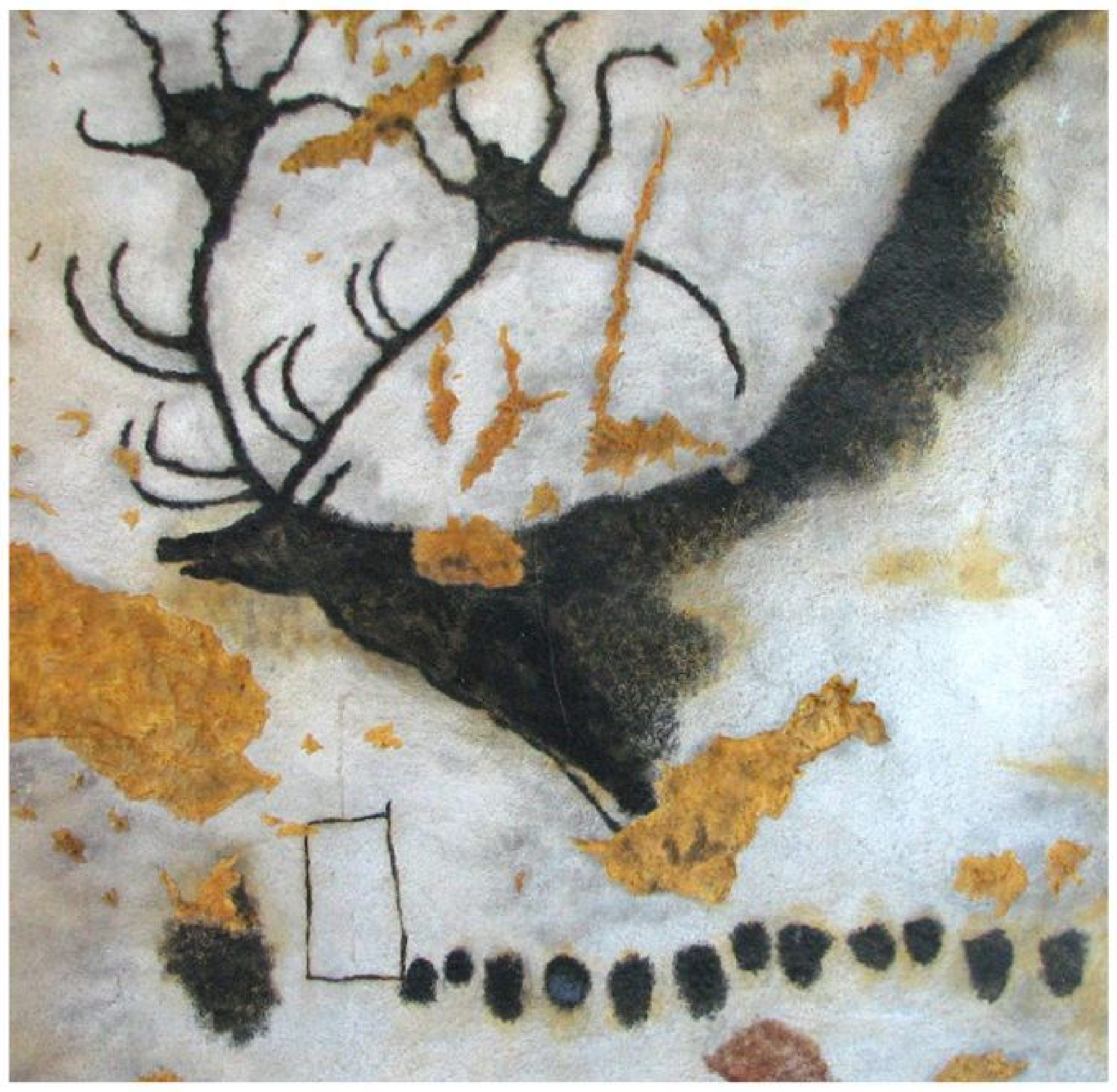
~2 MILLION YEARS AGO
Tools and food are transported to favoured resting and eating spots.

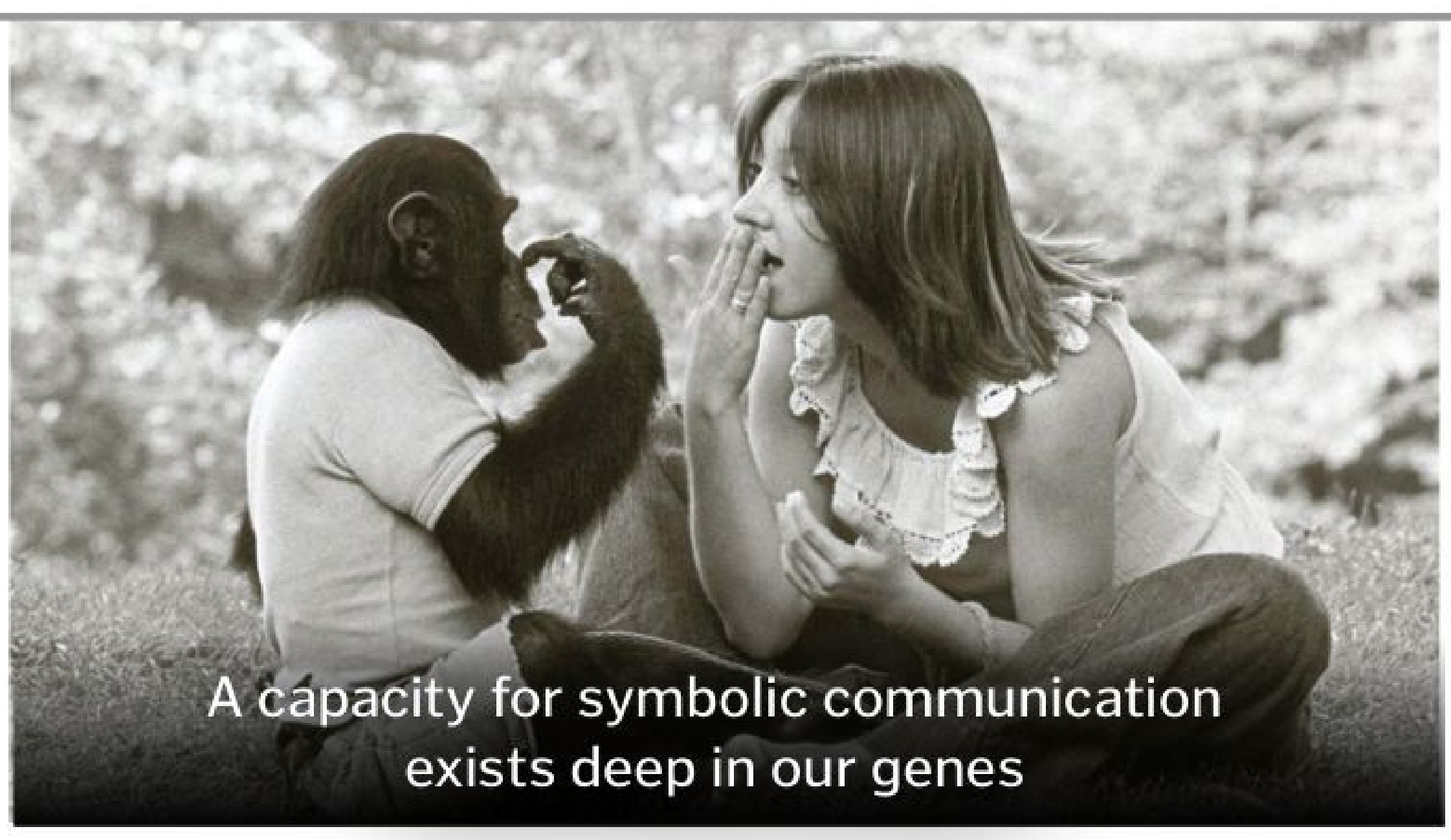
DID YOU KNOW? *Life expectancy for early humans was anywhere between 15 to 30 years*

Culture

How did early humans make sense of their world? Sadly, fossils are silent on the subject of culture – language, rituals, music and other forms of symbolic expression. But shell beads made in Africa 100,000 years ago and 40,000-year-old cave drawings in Europe are evidence of our ancestors' impulse to create, express and connect.

40,000-year-old cave painting of a giant deer, in Lascaux, France





A capacity for symbolic communication exists deep in our genes

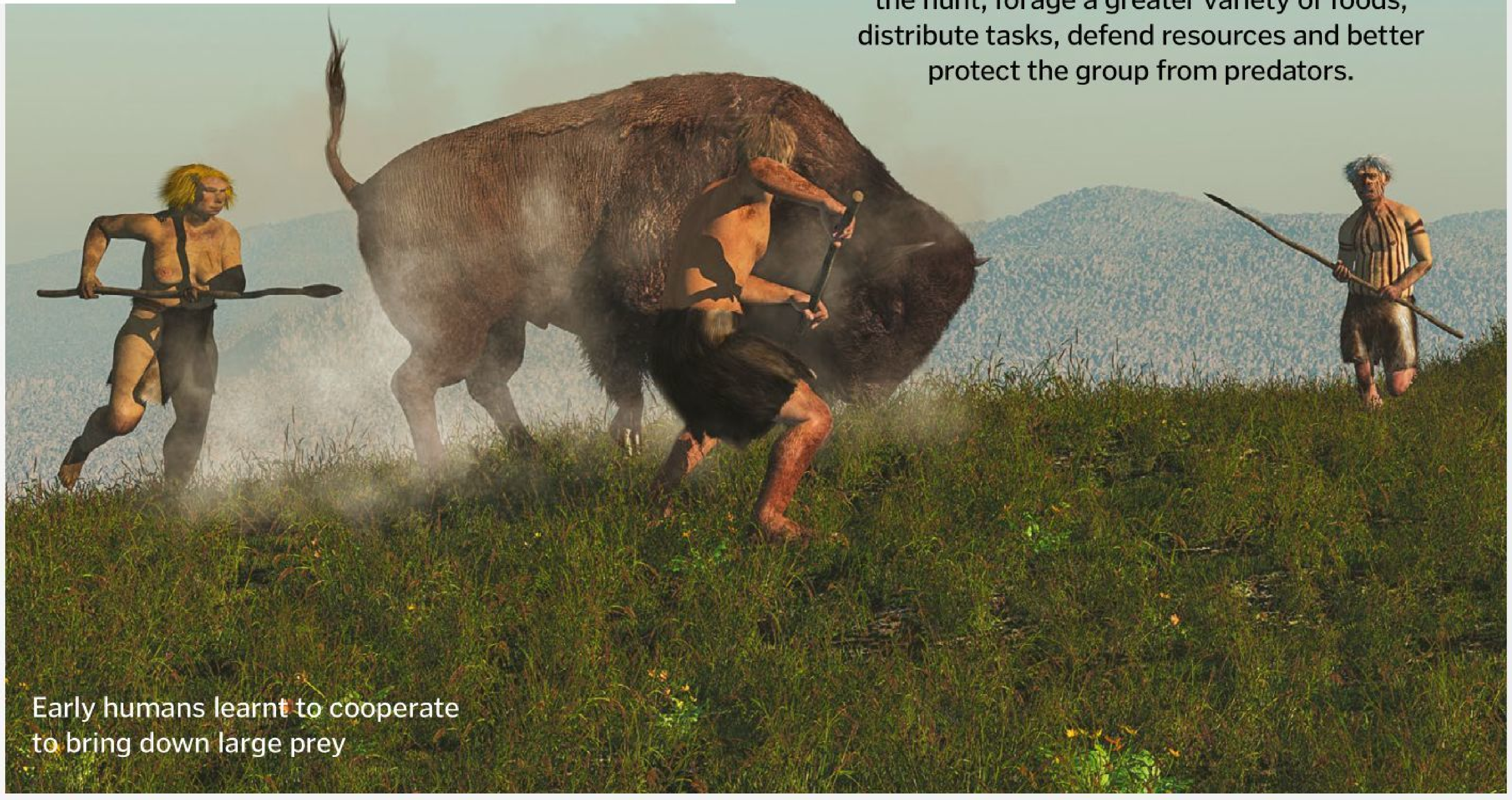
Communication

Many species communicate, but full language – with rules for combining sounds and words – appears to be uniquely human. One reason for this is that humans differ from most other primates in the way our larynx – or voice box – sits low in the throat. This allows us to shape sounds into speech, using our lips and tongues.

Precisely when and where language originated is unknown. The descended larynx evolved around 300,000 years ago, but experts believe spoken language only appeared in the last 100,000 years, probably developing out of a more basic 'proto-language' comprised of gestures and body language in addition to simple sounds.

Cooperation

When we work together cooperatively, we tend to achieve more in less time and with less effort. The same was true of our ancestors. By banding together, they could bring down larger animals in the hunt, forage a greater variety of foods, distribute tasks, defend resources and better protect the group from predators.



Early humans learnt to cooperate to bring down large prey

Brain size

In most mammals, brain size is proportional to body size. Most primates' brains exceed this ratio, but around two million years ago, our ancestors' brains started growing even larger. At the same time the brain was reordered, favouring the growth of some regions, such as those used for learning, over others, like those that govern smell.

Problem solving

As brain size and complexity increased, early humans became better equipped to tackle problems using logic and creativity. From tool-making to crossing continents to caring for the old and weak, it was this ability to interact with one another and the environment in novel ways that helped our ancestors survive in an unpredictable world.

Fire

Harnessing fire was a turning point in human history, but the evidence for how and when it happened is sparse and hotly contested.

Charred bones and ash suggest Homo ergaster interacted with fire in Africa as early as 1.5 million years ago, but whether the fires were wild or intentionally lit is a mystery. Better evidence of controlled use appears around 800,000 years ago; clusters of scorched tool-making debris, burned seeds, and wood mark more than a dozen early hearths across a site at Gesher Benot Ya'aqov in Israel.

Campfires not only provided warmth and protection from night-time predators; they also enabled food to be cooked, making it more digestible, and potentially influencing human brain evolution.

Tools of the age

Modern humans and our ancestors have been using tools for at least three million years. As intelligence increased, the tools that humans made became more sophisticated and specialised. Equipment for hunting, stripping animal carcasses and breaking open bones heralded an expansion in the ancient hominin diet, making more energy available for larger bodies and bigger brains.

Simple tools

Around 2.6 million years ago, early humans learnt to strike one stone with another to remove sharp-edged flakes. These simple tools represent a major evolutionary advance – the first technological thought. Toolmakers had to plan, learn from their mistakes, and select appropriate materials.

Refining the design

By 300,000 years ago, toolmakers understood how to prepare a stone 'core' so that flakes knocked from its surface with a single blow would have long, clean cutting edges. These could be refined for different purposes by tapping smaller flakes off one or both sides.

Intricate devices

Around 50,000 years ago, modern humans living in Ice Age Europe began working bone, ivory and antler into intricate and specialised tools including needles, spear tips, fishhooks and harpoons. These materials are awkward to work with, and the tools are a testament to the manual dexterity and mental acuity of their makers.

1.95 MILLION YEARS AGO
Homo erectus gives up climbing entirely, in favour of walking.

1.9 MILLION YEARS AGO
Newly carnivorous digestive tracts become shorter; brains and bodies become larger.

1.89 MILLION YEARS AGO
Homo erectus develops long legs and begins roaming faster and further.

1.8 MILLION YEARS AGO
Early humans develop a modern-type foot arch to support bipedal motion.

How we conquered the planet

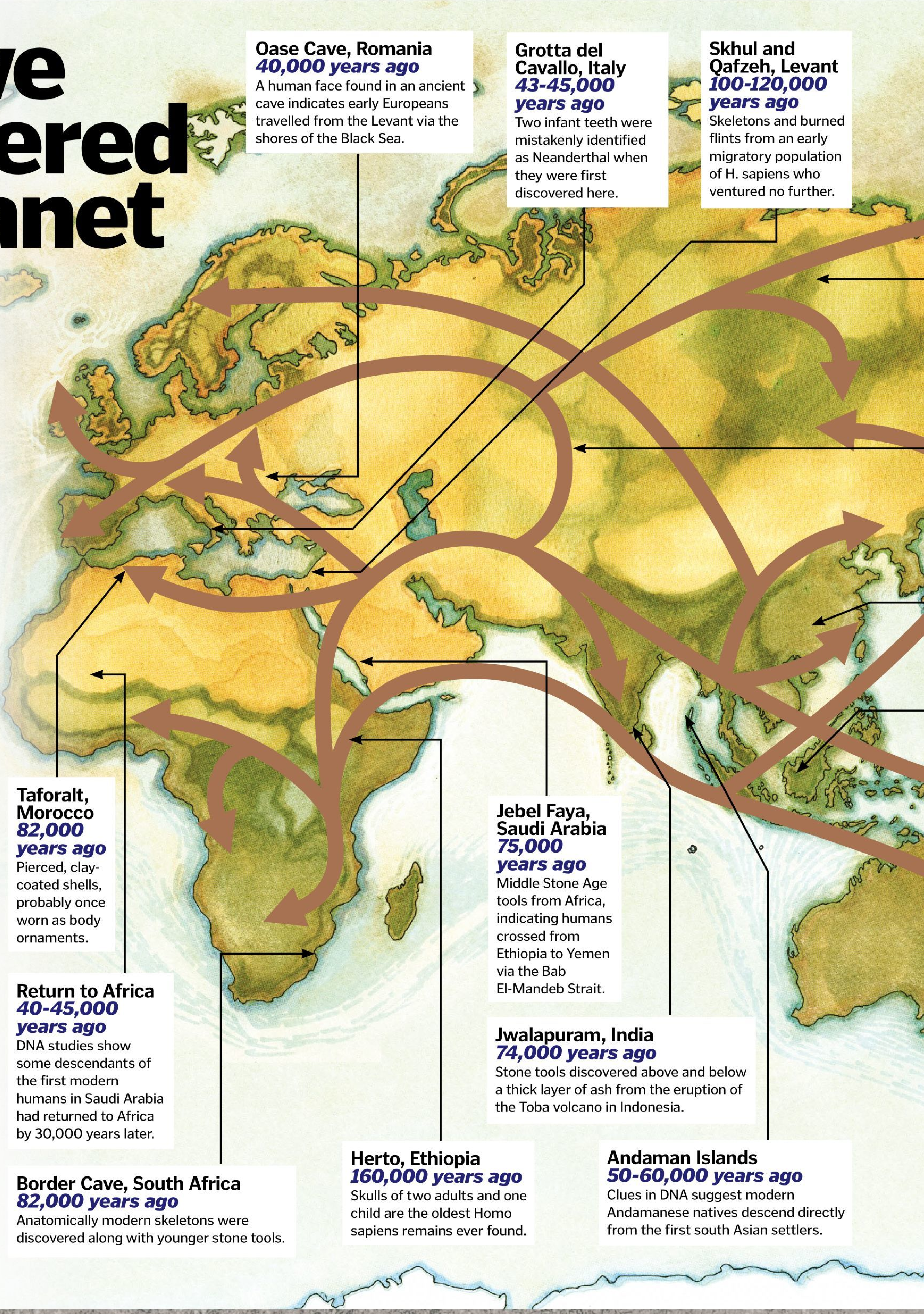
Humans went from African natives to citizens of the world

In our brief 200,000 years on Earth, Homo sapiens – unlike any of the human species before us – has managed to colonise the entire globe. But we were not the first to venture beyond Africa. Some of our ancestors took those initial steps at least 1.8 million years ago.

The first waves of adventurous hominins travelled east towards Asia, before eventually moving west and north into Europe. Homo erectus spread throughout Asia, reaching as far south as Java, and Homo heidelbergensis dispersed through both Asia and Europe.

As for our own species, all evidence suggests that we lived in Africa for the first 100,000 years of our 200,000-year existence. After a shaky first migratory attempt, it was another 30,000 years before we struck out again. This time marked the start of a mass exodus; Homo sapiens spread rapidly to all continents except Antarctica within 50,000 years, making us one of the most invasive species the world has ever known.

Why the itchy feet? Some scientists think we simply followed the roaming animals we ate; certainly other large predatory species made similar territorial expansions alongside us. Other experts hold the more romantic view that wanderlust is simply part of what makes us human.



Oase Cave, Romania
40,000 years ago
A human face found in an ancient cave indicates early Europeans travelled from the Levant via the shores of the Black Sea.

Grotta del Cavallo, Italy
43-45,000 years ago
Two infant teeth were mistakenly identified as Neanderthal when they were first discovered here.

Skhul and Qafzeh, Levant
100-120,000 years ago
Skeletons and burned flints from an early migratory population of H. sapiens who ventured no further.

Taforalt, Morocco
82,000 years ago
Pierced, clay-coated shells, probably once worn as body ornaments.

Return to Africa
40-45,000 years ago
DNA studies show some descendants of the first modern humans in Saudi Arabia had returned to Africa by 30,000 years later.

Border Cave, South Africa
82,000 years ago
Anatomically modern skeletons were discovered along with younger stone tools.

Herto, Ethiopia
160,000 years ago
Skulls of two adults and one child are the oldest Homo sapiens remains ever found.

Jebel Faya, Saudi Arabia
75,000 years ago
Middle Stone Age tools from Africa, indicating humans crossed from Ethiopia to Yemen via the Bab El-Mandeb Strait.

Jwalapuram, India
74,000 years ago
Stone tools discovered above and below a thick layer of ash from the eruption of the Toba volcano in Indonesia.

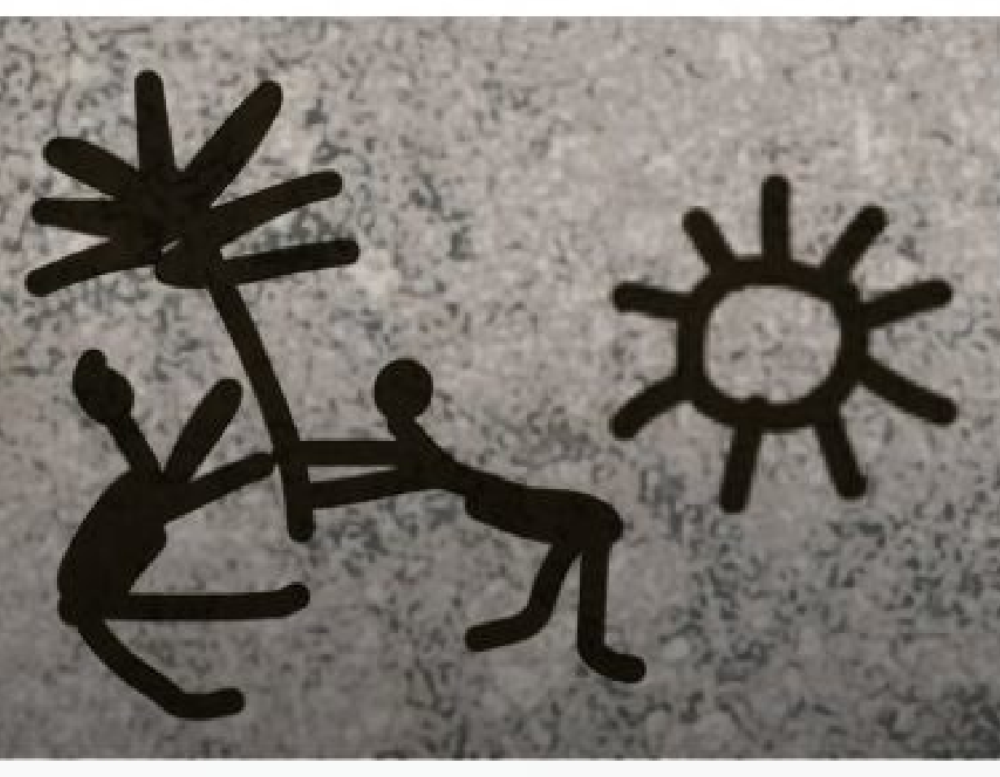
Andaman Islands
50-60,000 years ago
Clues in DNA suggest modern Andamanese natives descend directly from the first south Asian settlers.

1.8 MILLION YEARS AGO
Homo erectus becomes the first hominin to venture beyond Africa.

1.6 MILLION YEARS AGO
Neanderthals invent a hand axe – the first tool with well-defined form.

1.3 MILLION YEARS AGO
The Homo genus first spreads to Europe.

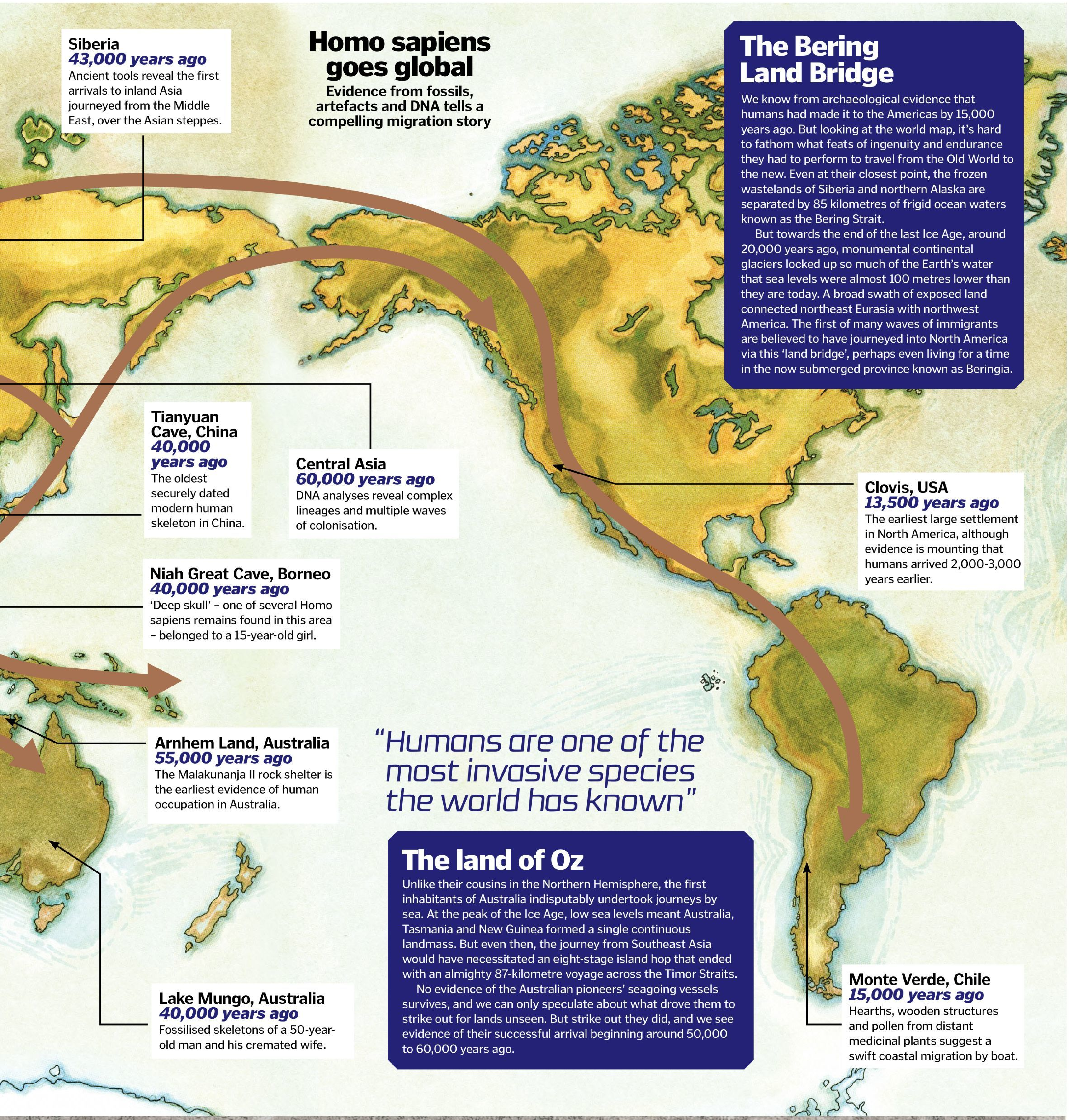
800,000 YEARS AGO
Early humans start to control fire and build hearths.



DID YOU KNOW? *The oldest Homo sapiens remains were discovered in Ethiopia, Africa*

Homo sapiens goes global

Evidence from fossils, artefacts and DNA tells a compelling migration story



Siberia
43,000 years ago
Ancient tools reveal the first arrivals to inland Asia journeyed from the Middle East, over the Asian steppes.

Tianyuan Cave, China
40,000 years ago
The oldest securely dated modern human skeleton in China.

Central Asia
60,000 years ago
DNA analyses reveal complex lineages and multiple waves of colonisation.

Niah Great Cave, Borneo
40,000 years ago
'Deep skull' – one of several Homo sapiens remains found in this area – belonged to a 15-year-old girl.

Arnhem Land, Australia
55,000 years ago
The Malakunanja II rock shelter is the earliest evidence of human occupation in Australia.

Lake Mungo, Australia
40,000 years ago
Fossilised skeletons of a 50-year-old man and his cremated wife.

Clovis, USA
13,500 years ago
The earliest large settlement in North America, although evidence is mounting that humans arrived 2,000-3,000 years earlier.

Monte Verde, Chile
15,000 years ago
Hearths, wooden structures and pollen from distant medicinal plants suggest a swift coastal migration by boat.

The Bering Land Bridge

We know from archaeological evidence that humans had made it to the Americas by 15,000 years ago. But looking at the world map, it's hard to fathom what feats of ingenuity and endurance they had to perform to travel from the Old World to the new. Even at their closest point, the frozen wastelands of Siberia and northern Alaska are separated by 85 kilometres of frigid ocean waters known as the Bering Strait.

But towards the end of the last Ice Age, around 20,000 years ago, monumental continental glaciers locked up so much of the Earth's water that sea levels were almost 100 metres lower than they are today. A broad swath of exposed land connected northeast Eurasia with northwest America. The first of many waves of immigrants are believed to have journeyed into North America via this 'land bridge', perhaps even living for a time in the now submerged province known as Beringia.

> *"Humans are one of the most invasive species the world has known"*

The land of Oz

Unlike their cousins in the Northern Hemisphere, the first inhabitants of Australia indisputably undertook journeys by sea. At the peak of the Ice Age, low sea levels meant Australia, Tasmania and New Guinea formed a single continuous landmass. But even then, the journey from Southeast Asia would have necessitated an eight-stage island hop that ended with an almighty 87-kilometre voyage across the Timor Straits.

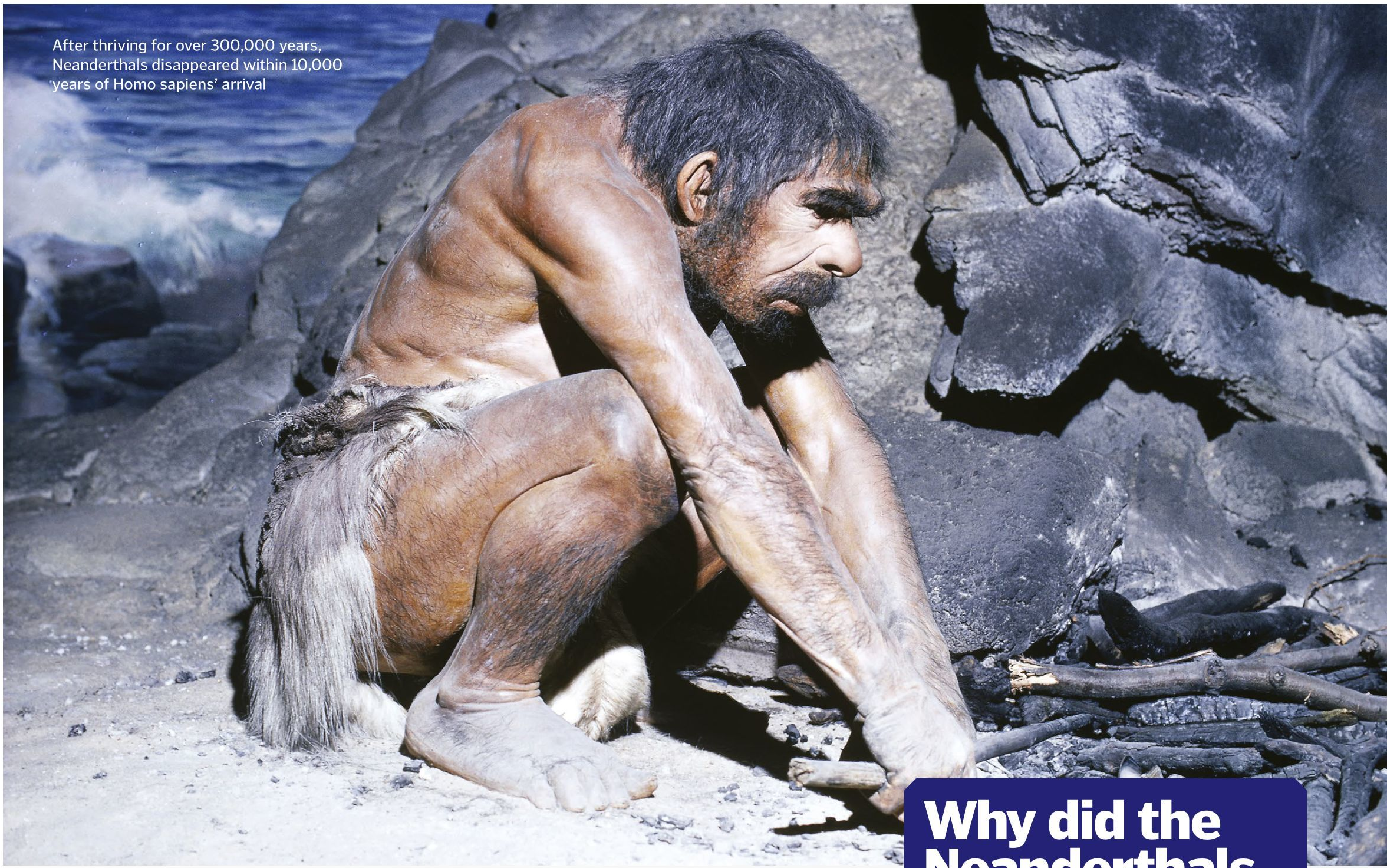
No evidence of the Australian pioneers' seagoing vessels survives, and we can only speculate about what drove them to strike out for lands unseen. But strike out they did, and we see evidence of their successful arrival beginning around 50,000 to 60,000 years ago.

200,000-800,000 YEARS AGO
Dramatic climate change spurs rapid evolution of larger, more complex brains.

400,000 YEARS AGO
Wooden spears are used to hunt large animals from safer distances.

400,000 YEARS AGO
Shelters are constructed to protect families or social groups from predators and elements.

300,000 YEARS AGO
Toolmakers produce long, clean blades by striking stone cores.



After thriving for over 300,000 years, Neanderthals disappeared within 10,000 years of Homo sapiens' arrival

Surviving adversity

How modern humans overcame threats and evaded extinction

After over six million years of human evolution, Homo sapiens is the only species left standing. What is the secret to our success? Scientists believe it lies in our adaptability, our capacity for abstract thought and our ability to cooperate.

Indeed, no other animal species has adapted to as wide a range of habitats and such divergent pursuits as modern humans. As successive waves flowed out of Africa and dispersed throughout the world, we learned in each new place how to find and eat local food and to survive different climate conditions.

We could not have done this without technological ingenuity, nor without the cultural transmission of ideas – the ability to mimic one another, communicate concepts, and learn new skills. This allows the work of the most skilled or intelligent to benefit entire populations, instead of forcing each new generation to re-invent the wheel.

These characteristics made us resilient in the face of change. During the Ice Age winters of 15,000 years ago, for example, modern humans in eastern Europe came up with clever ways to cope with the cold. By sewing clothes from animal hides, building shelters from mammoth bones, preserving dwindling food supplies in the permafrost and using fire to keep warm, they were able to ride out the tough times together and ensure the survival of the species.

Why did the Neanderthals die out?

Between 35,000 and 45,000 years ago, modern humans spread throughout Europe, while the Neanderthals, present since over 250,000 years earlier, mysteriously disappeared. Many scientists suspect the two events are closely linked, and argue that Homo sapiens out-competed their close cousins for resources and perhaps even actively attacked them.

Others wonder whether the narrow Neanderthal gene pool might have been to blame. Some studies suggest that the Neanderthal population never grew bigger than a few thousand individuals. The lack of genetic diversity and small population size would have made them vulnerable to infections, radical shifts in the environment and natural disasters.

250,000 YEARS AGO
Pieces of pigment are used as chunky crayons to communicate with symbols.

195,000 YEARS AGO
Homo sapiens evolves in Africa during a time of dramatic climate change.

160,000 YEARS AGO
Homo sapiens collects and cooks shellfish on the southern shores of Africa.

130,000 YEARS AGO
Modern humans exchange resources over long distances.

DID YOU KNOW? *The next stage of human evolution could involve the colonisation of Mars*

A thriving species

How soil, society and science elevated modern humans

The moment when modern humans transitioned from merely surviving to convincingly thriving happened somewhere around 12,000 years ago, coinciding with the advent of agriculture.

For millions of years leading up to this time, early and modern humans alike were preoccupied with foraging, hunting and scavenging food. But once we discovered that we could control the growth and breeding of certain plants and animals, we quickly became farmers and herders.

As these practices gained momentum, settlements began to form around them. These grew from villages to towns to cities as food became more plentiful. Within them, the human population began to explode, eventually reaching levels where we were unlikely to be wiped out by anything less than a global catastrophe.

Cities became the focus of social interaction, idea exchange and technological innovation. The ballooning population allowed knowledge and creative expression to flourish, as individuals were able to specialise and learn from each other.

Over centuries and millennia, the rate of progress has continued to accelerate and innovations – from the printing press to the Internet, from surgery to vaccines, from the wheel to global air travel – continue to make our lives longer, safer and more rewarding.

Humanity's vast accumulation of medical expertise keeps us healthier than ever before

Where are we headed?

Of course, the story of humans is not over. Pressures of diet and disease, as well as our increasingly globalised lifestyles, continue to influence our genetic trajectory. In fact, some scientists think human evolution is accelerating. So what does our future hold?

For the first time in history, genetic engineering may soon give us direct influence over our own or our children's genes. But superhuman bodies will be useless if we continue to neglect the planet that sustains us. Despite our miserable environmental track record, we have the unique ability to comprehend the future consequences of our actions; the question remains whether we can learn to look beyond our immediate, individual interests.

If the planet can't meet the needs of the heaving population, we might eventually have to turn our gaze outwards. Colonisation of space might even result in new species of humans developing as populations are isolated by distance and interbreeding becomes impossible.

Throughout history, humans have followed the urge to venture into the unknown

> *"The ballooning population allowed knowledge and creativity to flourish"*

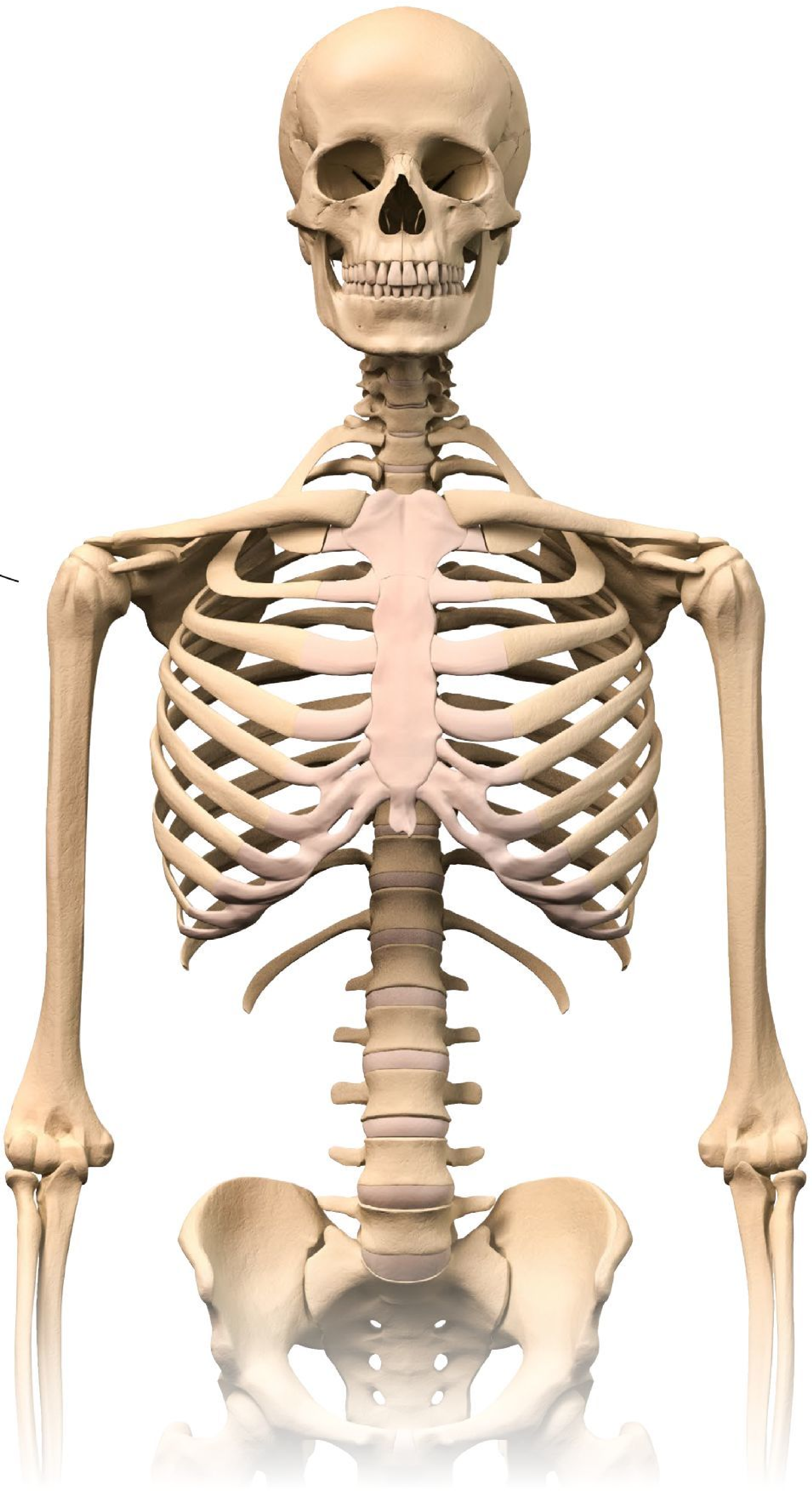
100,000 YEARS AGO
The first evidence of an intentional burial with ritual elements.

70,000 YEARS AGO
The major dispersal of Homo sapiens beyond Africa begins.

40,000 YEARS AGO
Modern humans create the first permanent drawings in Europe.

12,000 YEARS AGO
Agriculture begins to transform Earth's landscapes, first locally and then globally.

WHAT ARE WE MADE OF?

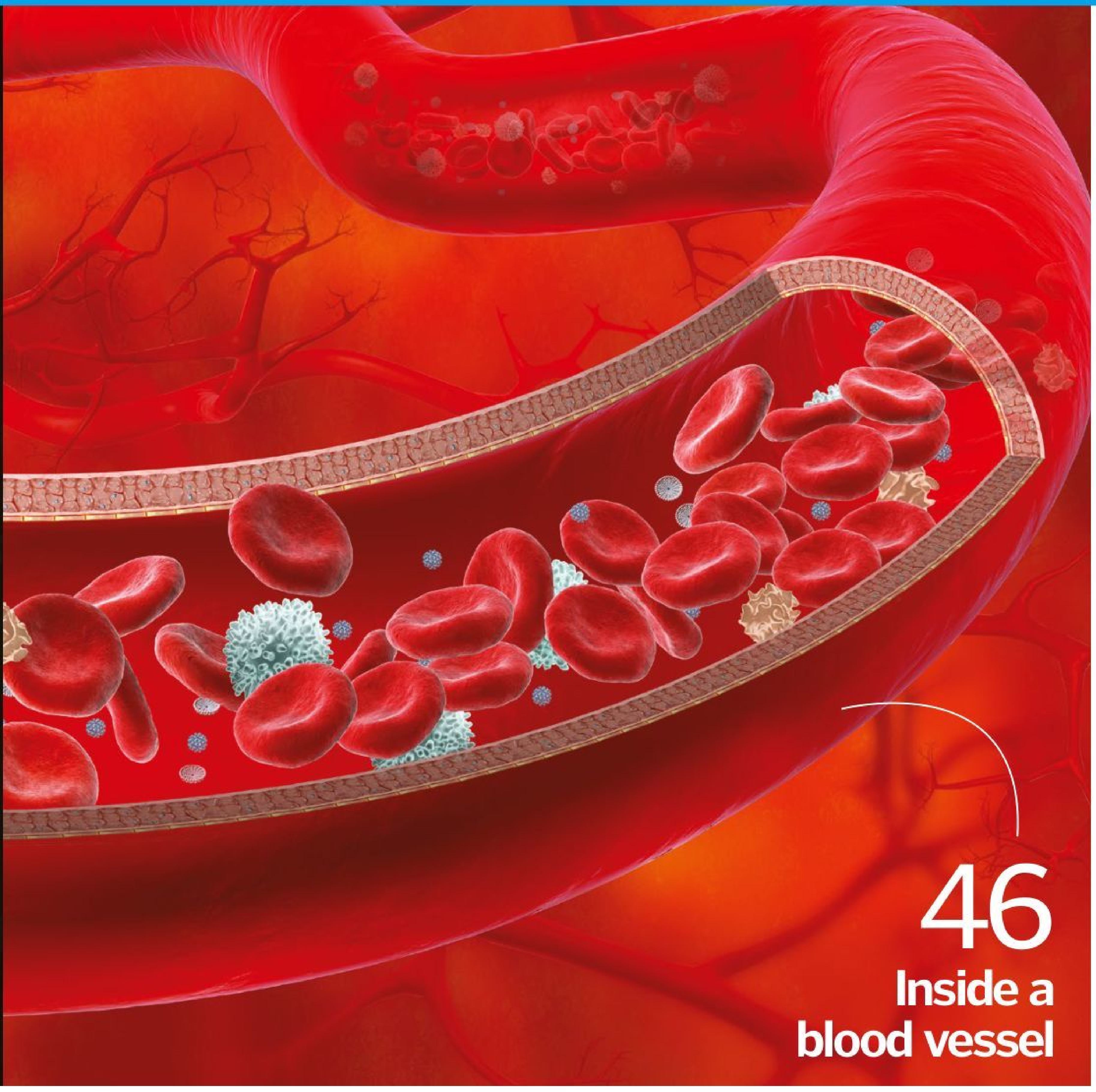


40
Your skeleton

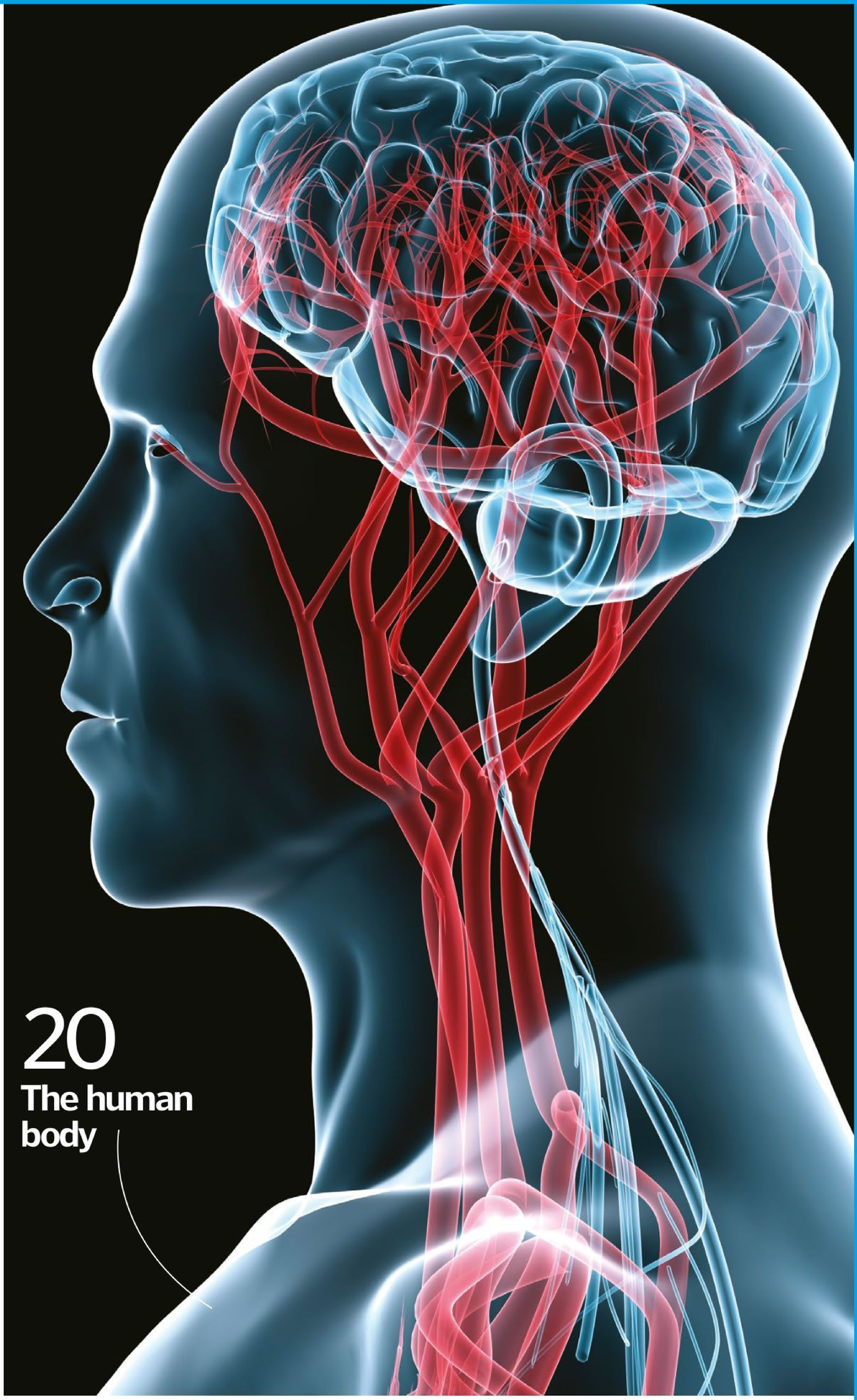
54
Muscle power

26
Your first year

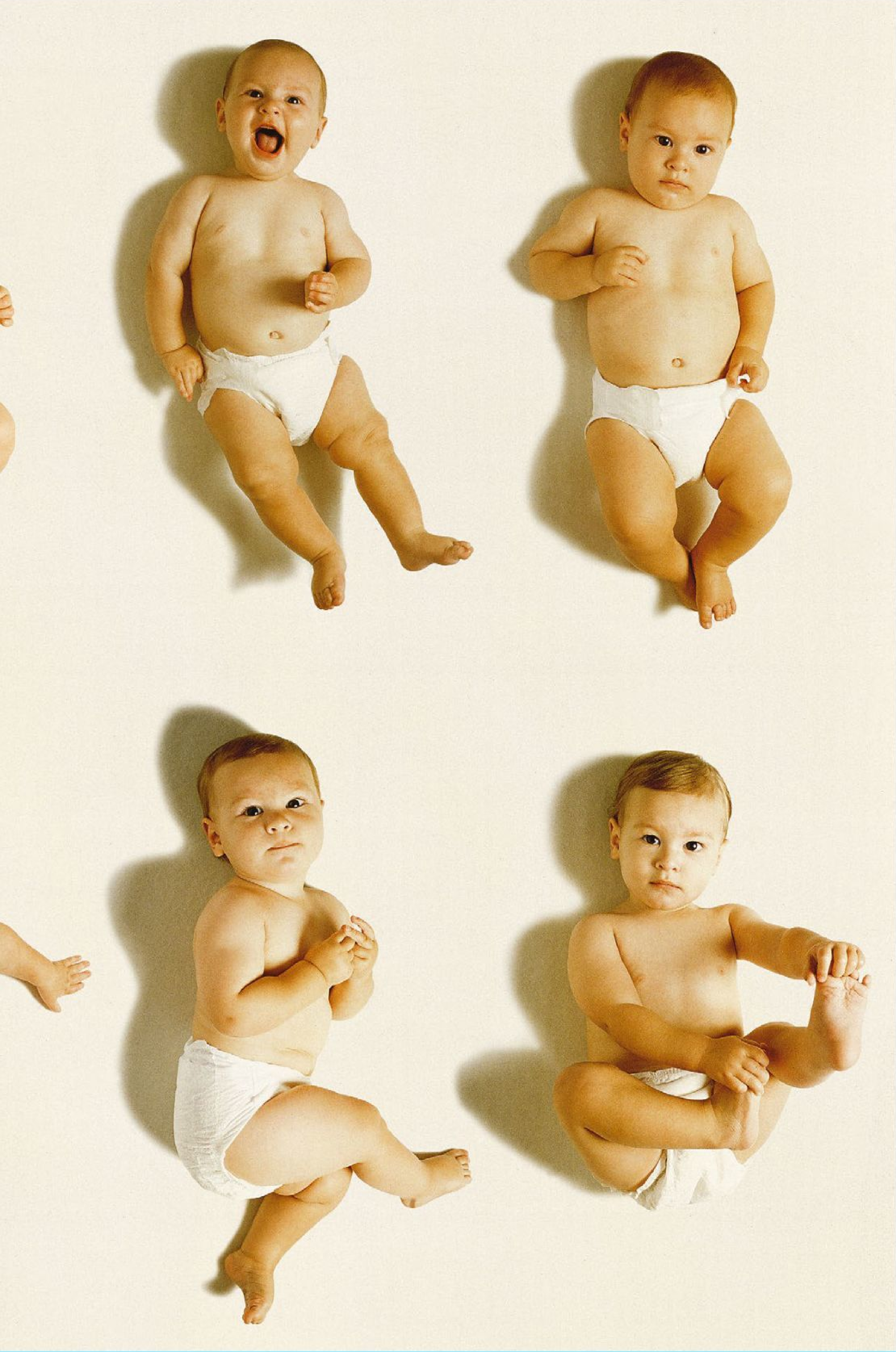
20 The human body
26 Your first year
32 Your amazing brain
40 Your skeleton
46 Inside a blood vessel
46 How cells work
47 The heart – a vital organ
48 Inside the liver and pancreas
50 What's inside your head
52 Inside the knee
53 What is thermoregulation?
54 Muscle power
58 Science of vision
62 The retina
64 The human pelvis
66 The lymphatic system

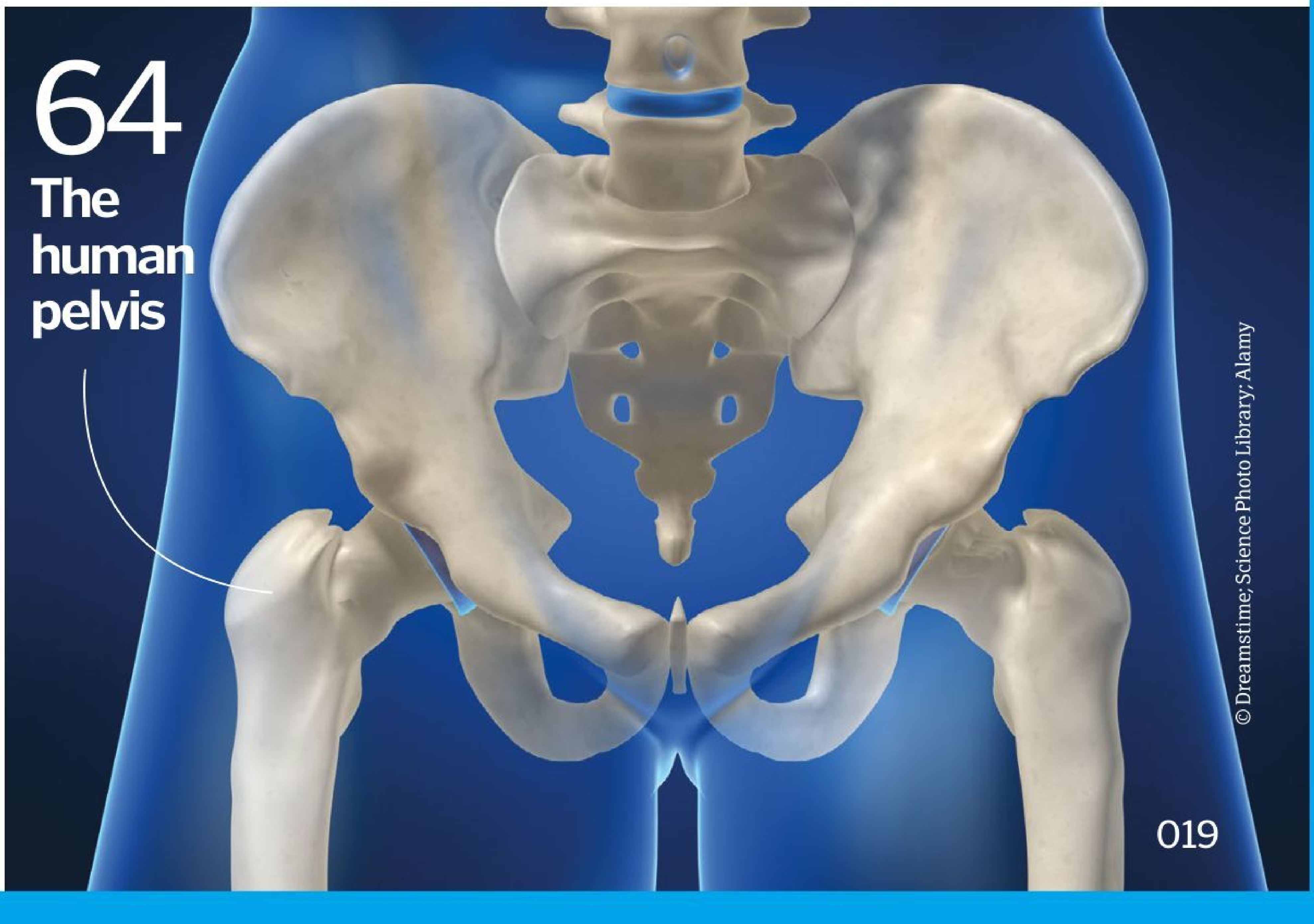


46 Inside a blood vessel



20 The human body

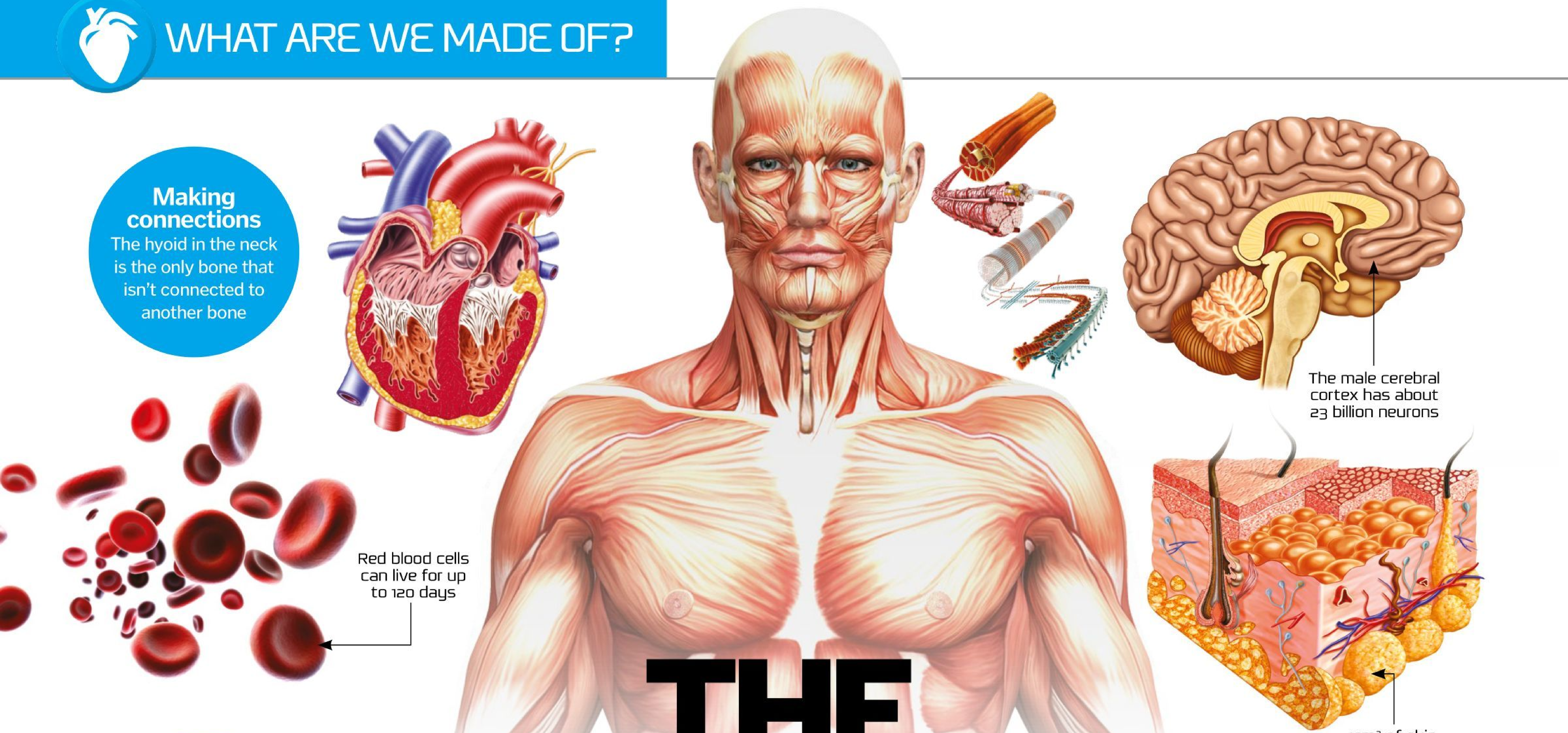




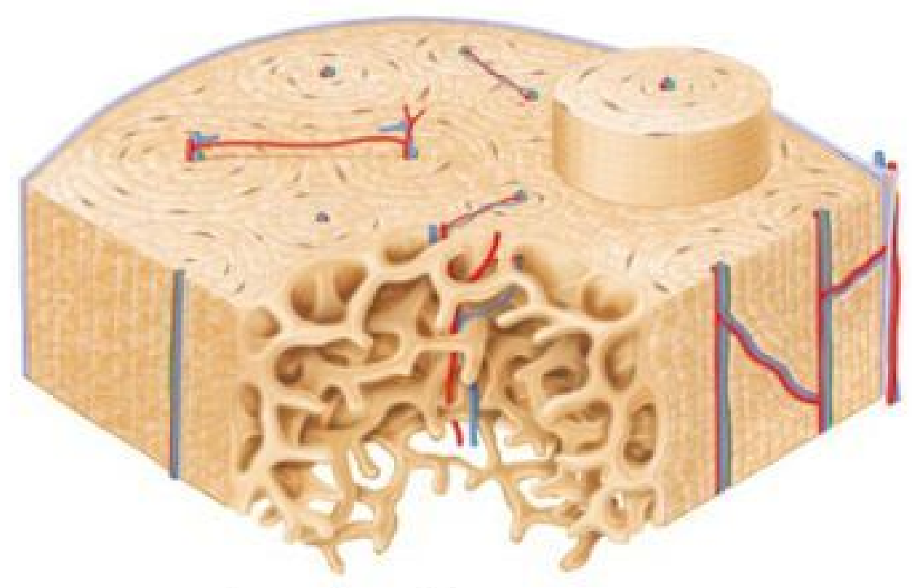
64 The human pelvis

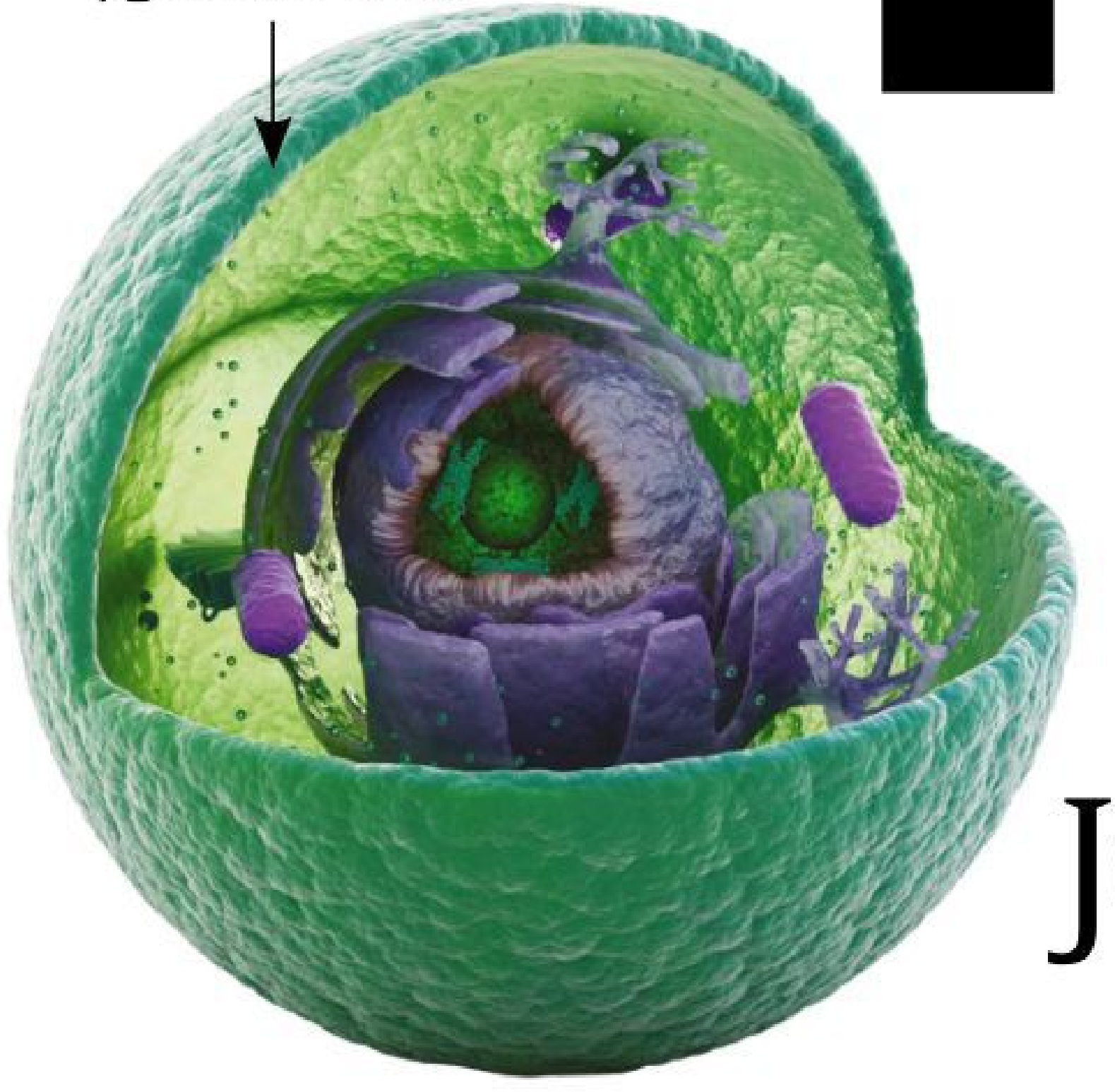
© Dreamstime; Science Photo Library; Alamy

Making connections
The hyoid in the neck is the only bone that isn't connected to another bone



The male cerebral cortex has about 23 billion neurons
Red blood cells can live for up to 120 days
1cm² of skin can contain 70cm of blood vessels





99% of the body is made of just 6 elements

THE HUMAN BODY

Journey inside the body to discover just what we are made of…

The human body is composed of an estimated 7 octillion (which written out is 7,000,000,000,000,000,000,000,000,000) atoms, making up over 75 trillion cells.

At the atomic level, the human body comprises about 60 elements, but the function of many of them is unknown. In fact, 99 per cent of the human body is made from just six elements (see chart for specific percentages).

Like all other life discovered to date, we are carbon-based; the biomolecules that make up our bodies are constructed using frameworks of carbon atoms. Carbon is almost unique among the elements; it is small in size and can make four covalent bonds to other atoms, allowing it to form the backbone of key molecules that form the human body, including proteins, fats, sugars and DNA. The bonds are strong enough to hold the molecules in a stable structure, but not so strong that they cannot be taken apart again, allowing the body to break and reform molecules over and over as required.

Calcium is the most abundant mineral in the human body, important for the regulation of protein production and activity.

Complex cascades of chemical reactions occur within the gel-like cytoplasm and organelles of cells – tiny structures that perform specific functions within a cell. Phosphorus is used to make adenosine triphosphate (ATP), which has high-energy phosphate bonds that can be broken in order to power cellular processes; ATP is essentially our cells' fuel.

Cells are coated in receptors and respond rapidly to environmental changes, communicating via chemical signals and electrical impulses. During embryonic development, chemical gradients tell developing cells where to go, and what cell type to become, resulting in a new person.

Interestingly, the majority of the cells in the human body are not human. Microbes make up between one and three per cent of our body mass and are hugely important for our proper functioning. They have 8 million different coding genes for making proteins, compared to less than 30,000 in the human genome.

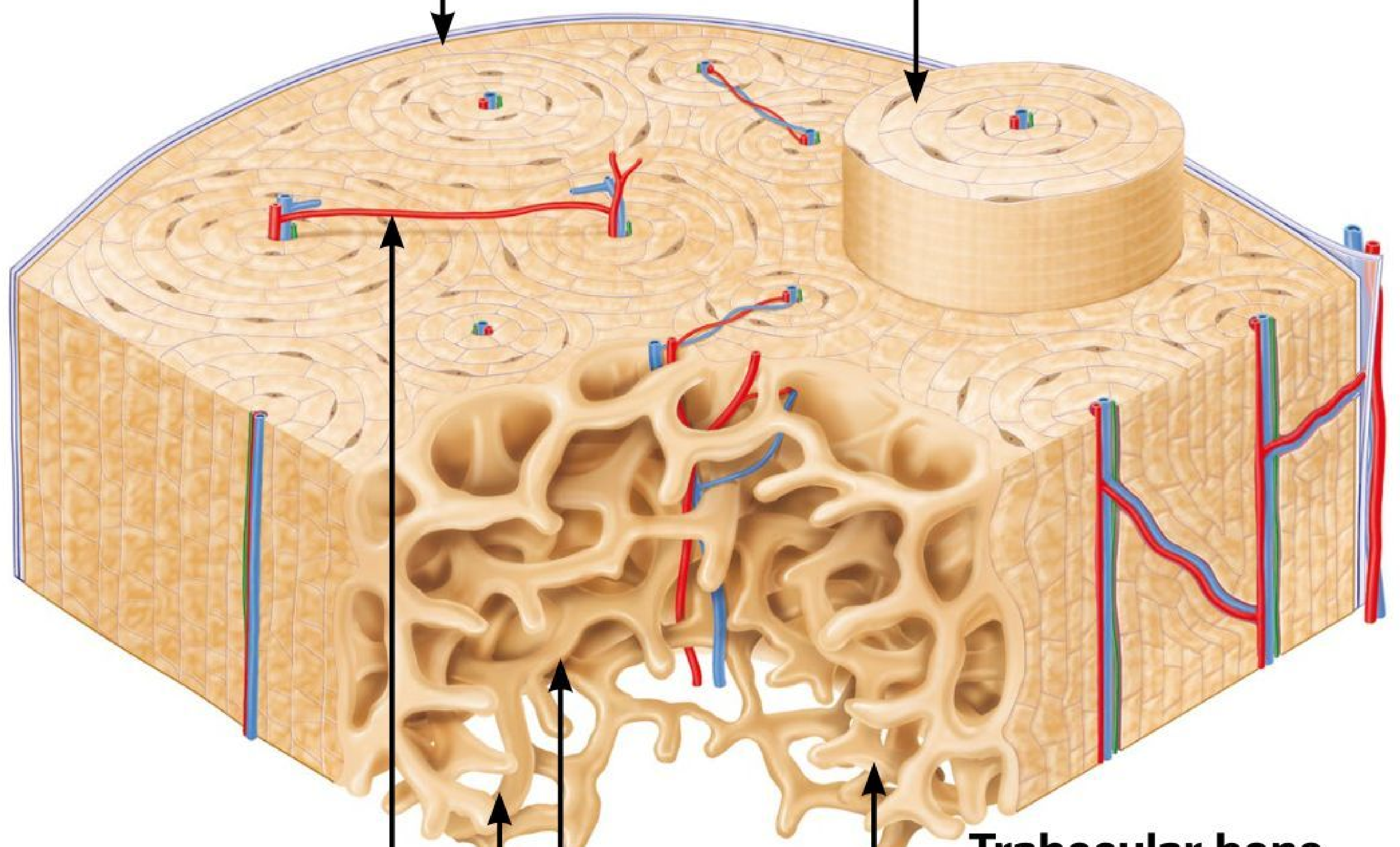
The bacteria that live in our digestive system provide essential support too; they ferment undigested carbohydrates, allowing us to access energy we couldn't otherwise digest, and they have a role in the production of vitamins like biotin and vitamin K. Their presence in the gut also prevents 'bad' bacteria from taking hold and making us unwell. Even more unusually, at least eight per cent of the human genome is viral in origin. Retroviruses are able to insert their DNA into our chromosomes, and at several points in human evolution genes that started out in viruses have become permanently entwined with our own genetic information.

How many hairs?
A human head has an average of 100,000 to 150,000 hairs

DID YOU KNOW? *Bone works like reinforced concrete with its collagen fibres the steel supports and the minerals cement*

The structure of bones

The long bones of the body, such as the femur (thighbone), contain two distinct types of bone



Osteocyte
The cells that form the bone matrix eventually become trapped in it. They help to regulate bone turnover.

Cortical bone
The tough outer layer of bones contains densely packed cylindrical structures – osteons – formed from concentric layers of bone tissue.

Blood vessels
Bone is a metabolically active tissue and a good blood supply allows for mineral exchange.

Trabecular bone
Within the ends of long bones is a looser, honeycomb structure, where calcium is released from storage as required.

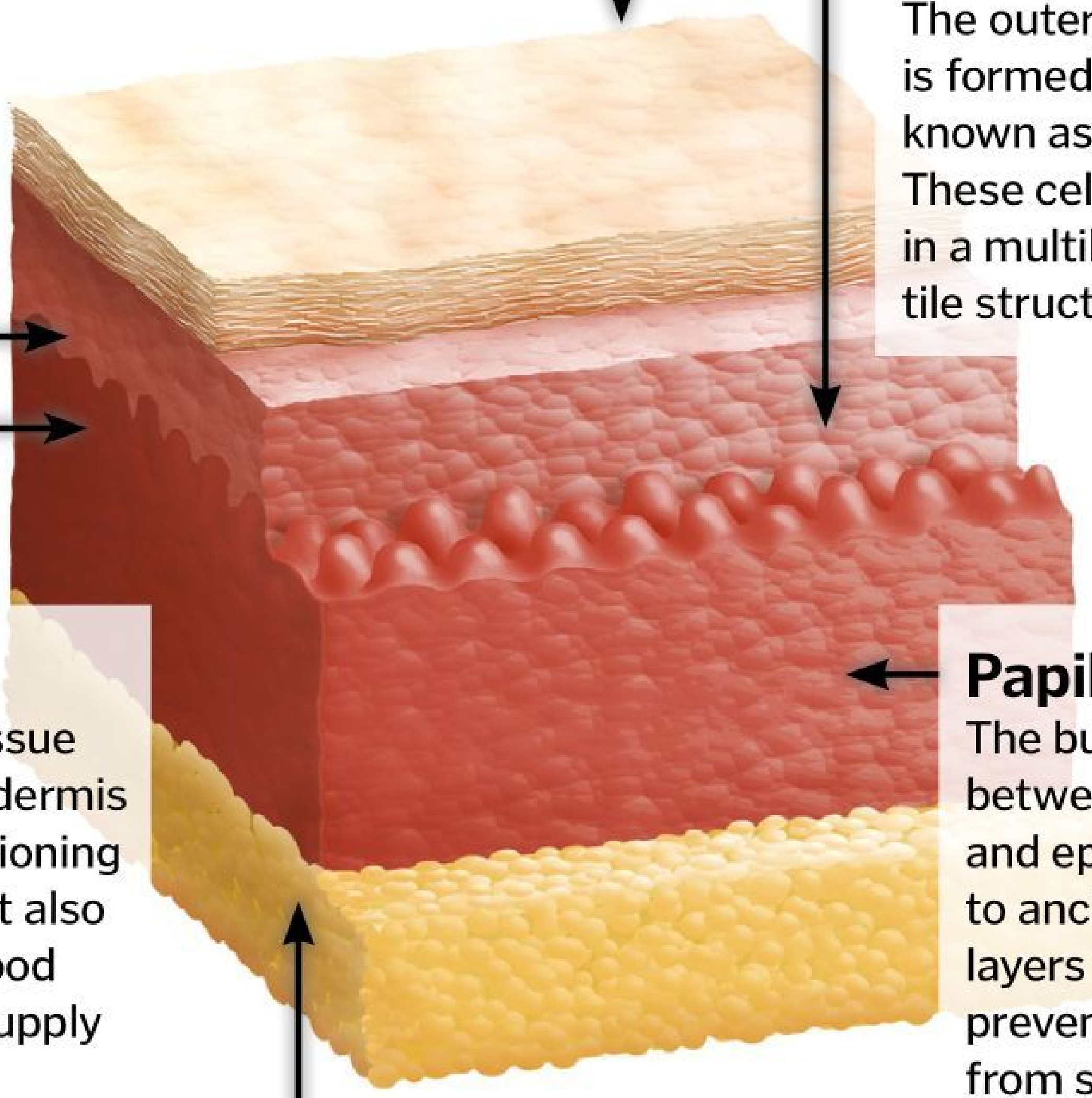
Osteoblast
Osteoblasts make new bone, producing the collagen scaffold and laying down minerals.

Osteoclast
Osteoclasts are related to cells of the immune system and digest old bone to release minerals and allow for remodelling.

Beneath the skin

Skin has several layers with a unique function

Largest organ of the body
The skin of a human adult measures two square metres (22 square feet)



Stem cells
A layer of stem cells at the base of the epidermis divides to form new skin cells, which push upwards to replace the dead ones.

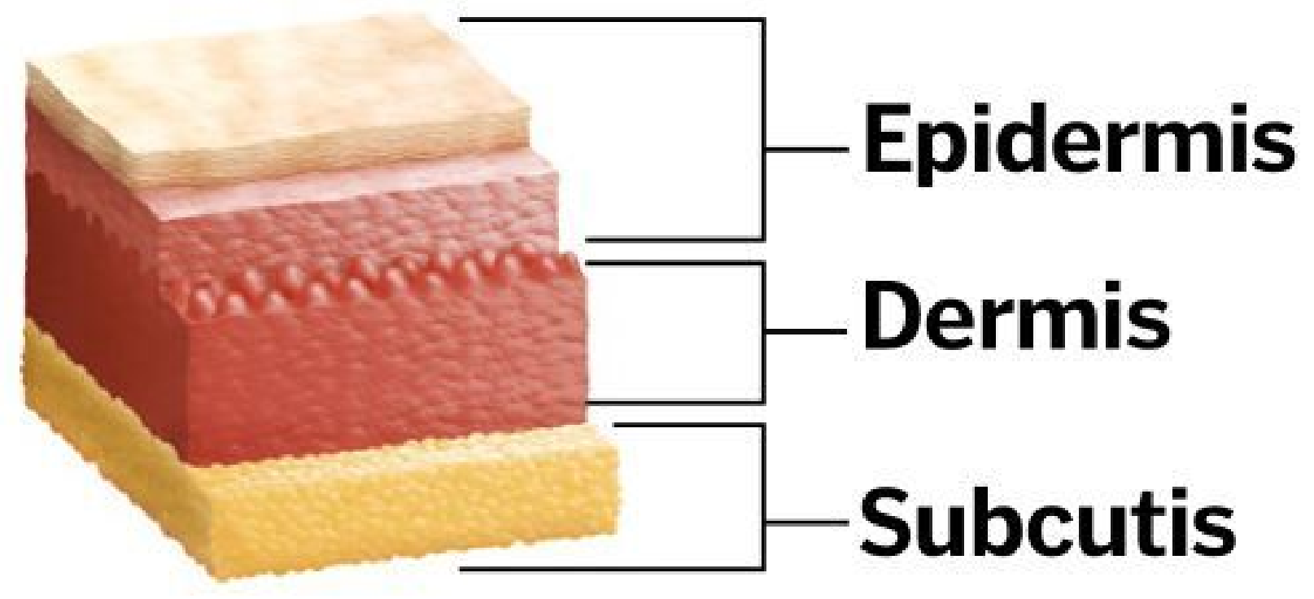
Cornified layer
The very outer layer of the skin consists entirely of flattened, dead cells. These provide a protective barrier.

Epidermis
The outer layer of skin is formed of cells known as keratinocytes. These cells arrange in a multilayered tile structure.

Dermis
Connective tissue below the epidermis provides cushioning and support. It also carries the blood vessels that supply the skin cells.

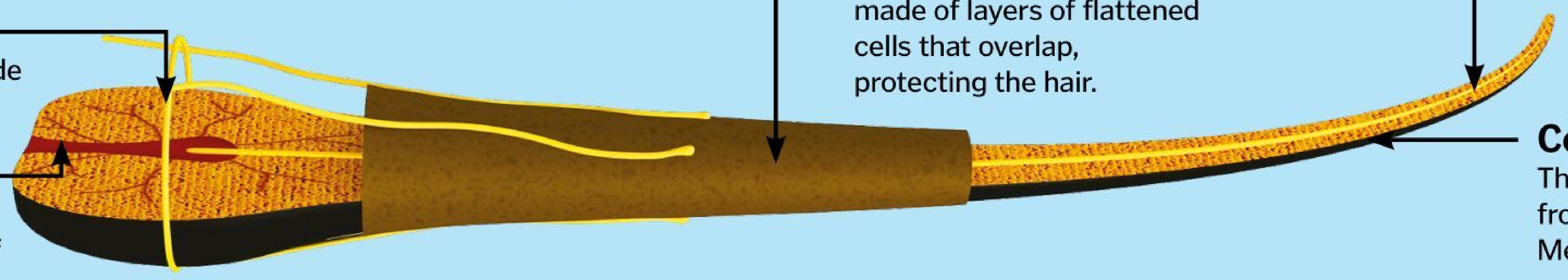
Papillae
The bumpy structure between the dermis and epidermis helps to anchor the two layers together, preventing them from slipping.

Fat
A layer of subcutaneous adipose tissue provides cushioning and insulation, as well as energy storage.



Hair under the microscope

A strand of hair can be divided into three distinct regions



Matrix
Cells of the matrix divide to produce new hair.

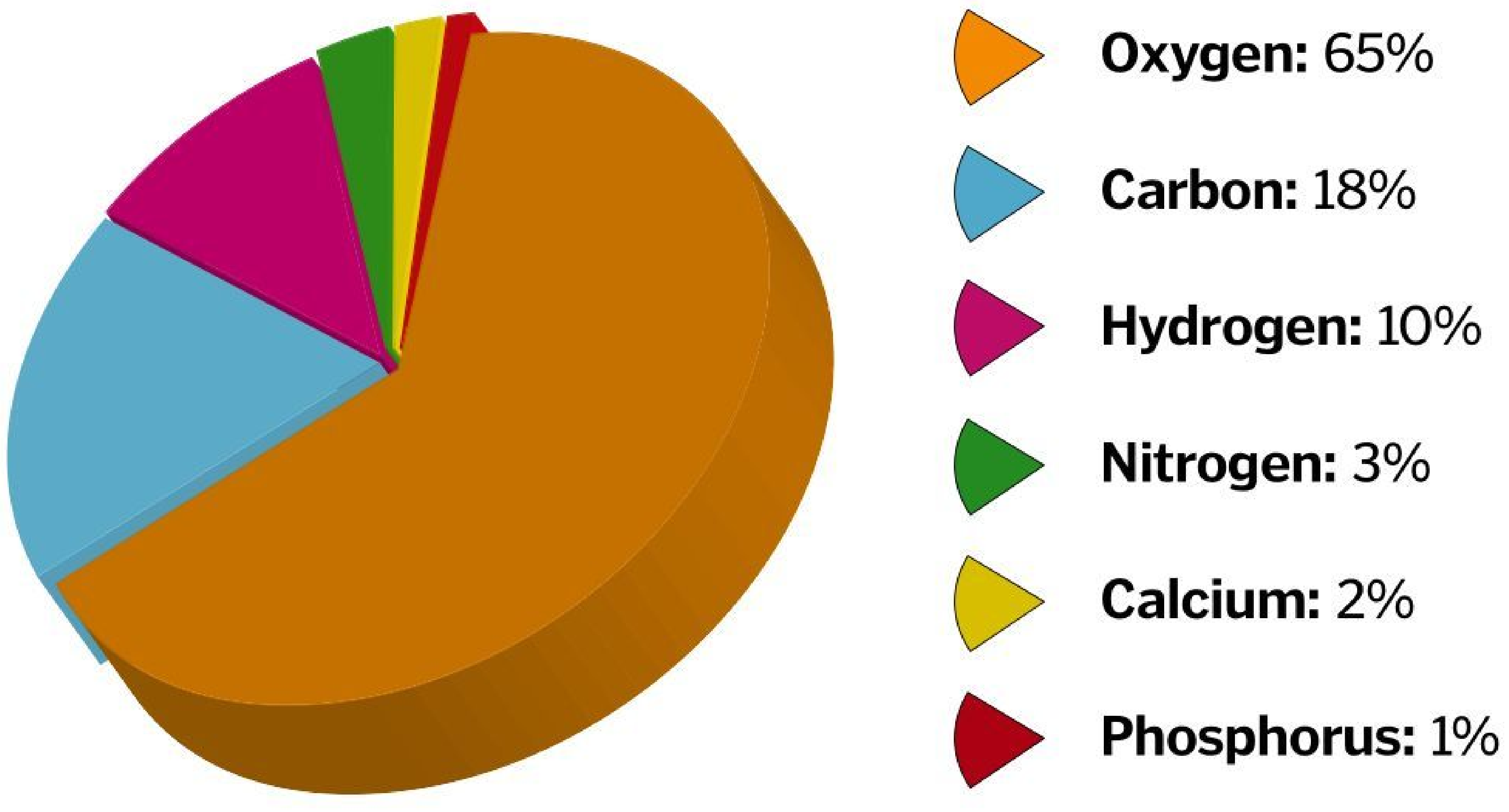
Papillae
Blood vessels supply nutrients to the cells of the matrix and root.

Cuticle
The outside of the hair is made of layers of flattened cells that overlap, protecting the hair.

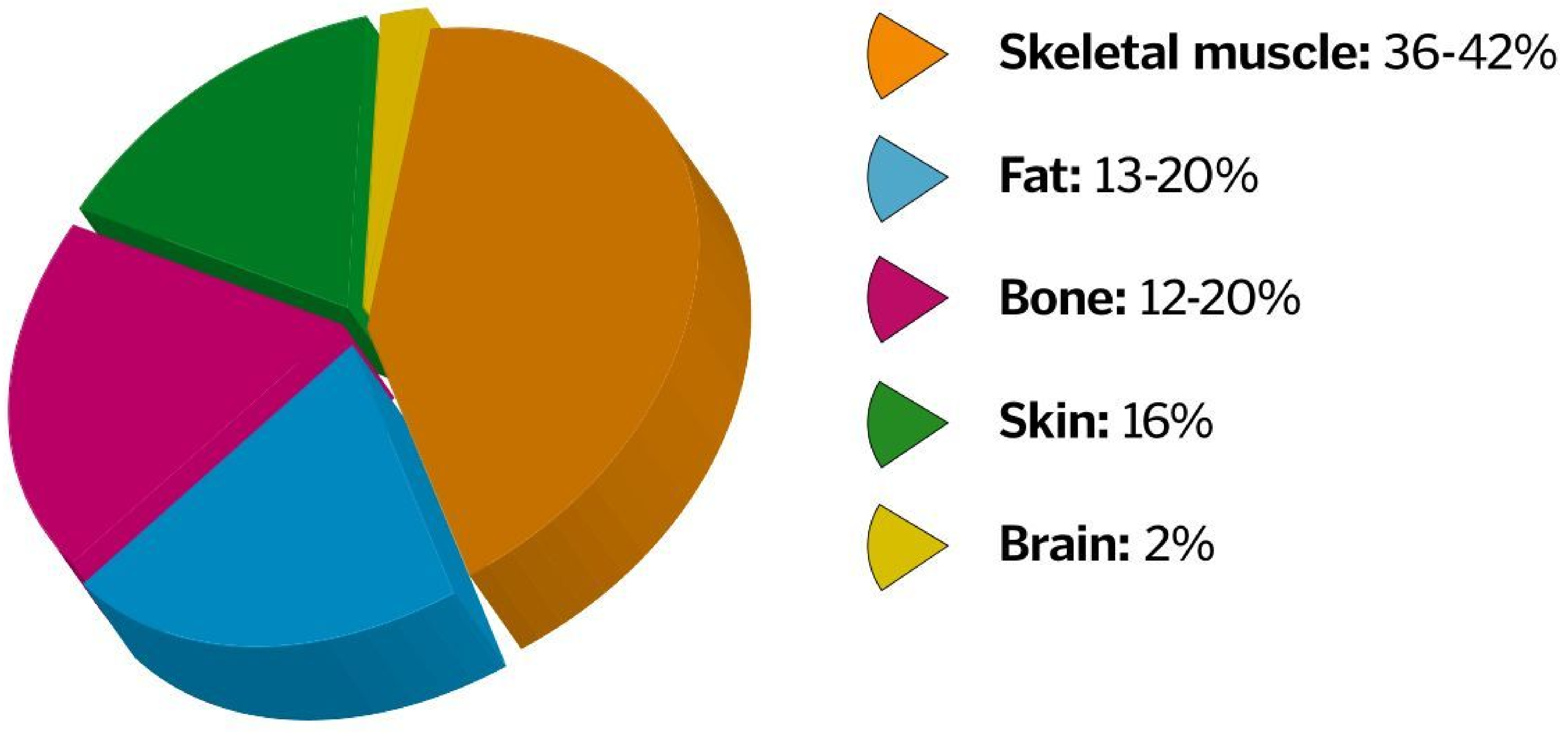
Medulla
An open, unstructured core runs up the centre of the hair.

Cortex
The body of the hair is made from coiled strands of keratin. Melanin granules within the cortex lend it its colour.

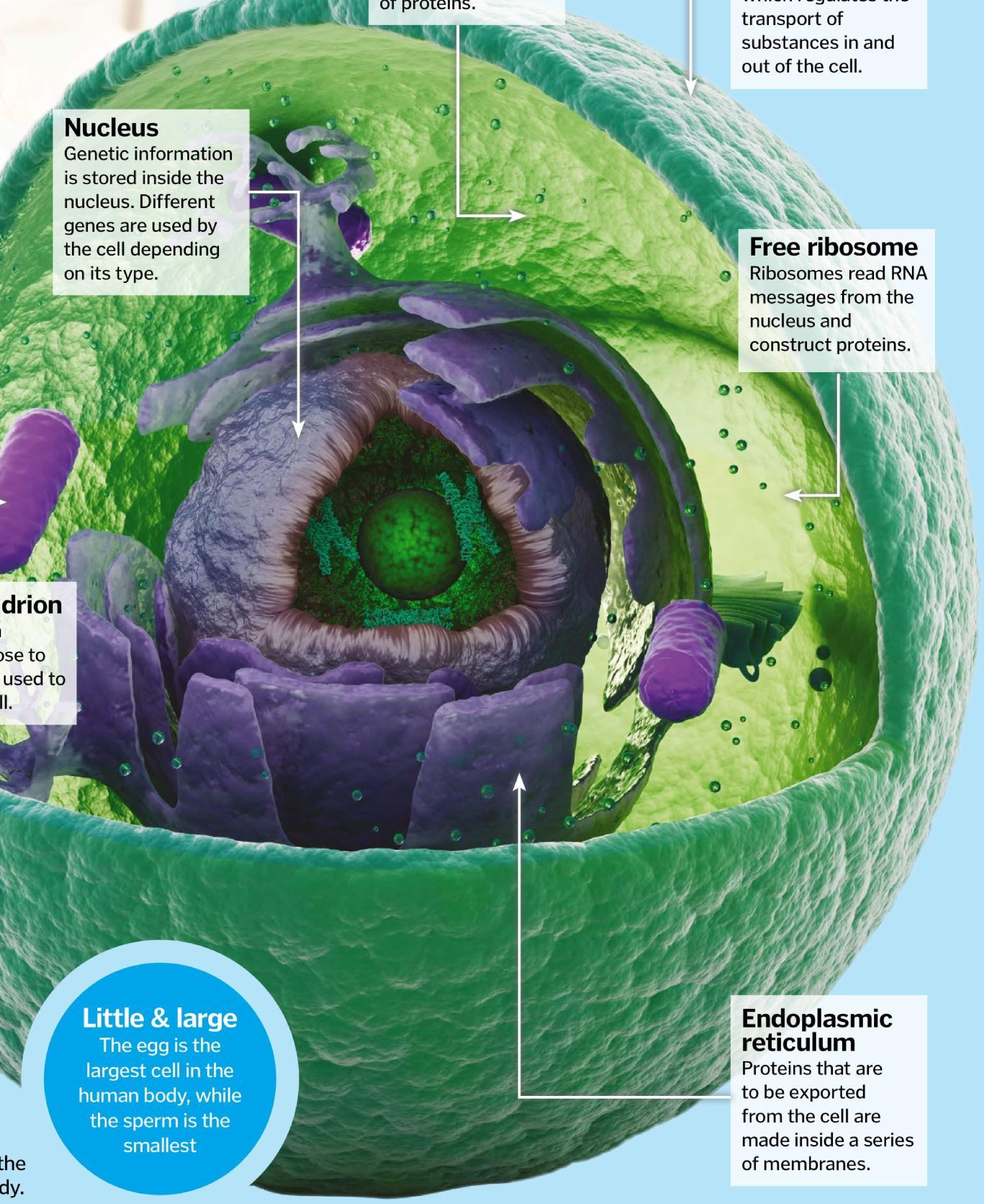
Six main elements of the body (99%)



Body composition by tissue type



The nucleus stores all sorts of genetic information



Cytoplasm
The cell is filled with a gel-like substance that contains thousands of proteins.

Cell membrane
The cell is enclosed in a membrane, which regulates the transport of substances in and out of the cell.

Nucleus
Genetic information is stored inside the nucleus. Different genes are used by the cell depending on its type.

Free ribosome
Ribosomes read RNA messages from the nucleus and construct proteins.

Mitochondrion
Mitochondria convert glucose to ATP, which is used to power the cell.

Endoplasmic reticulum
Proteins that are to be exported from the cell are made inside a series of membranes.

Close up with cells

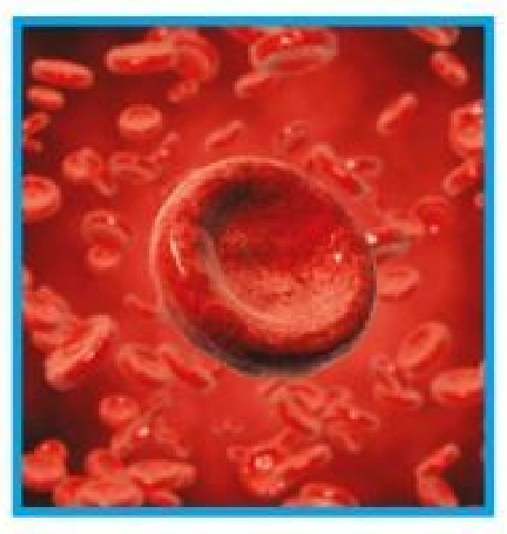
There are thought to be over 200 different types of cell in the human body, each specialised to perform a particular function. Despite these specialisms, their basic underlying biology is the same.

Cells contain a nucleus, which houses the 46 chromosomes, containing the complete set of instructions to synthesise all of the proteins found in the human body. Depending on the type of cell, different genes are switched on and off, determining which proteins the cell will produce.

Proteins for use inside the cell are created on ribosomes in the cytoplasm. The ribosomes read the genetic message and assemble the corresponding protein using amino acids as building blocks. Proteins to be exported from the cell – for example, antibodies or digestive enzymes – are constructed within a series of membranes. Here they gain a number of modifications which enable them to survive the harsh environment when they leave the cell to travel around the body.

Little & large
The egg is the largest cell in the human body, while the sperm is the smallest

Key cells of the body



Blood and immune cells

Type: Blood

The cells of the blood, including red blood cells and the white blood cells of the immune system are all produced in the bone marrow. Red blood cells lack a nucleus, enabling them to pack more of the oxygen-carrying protein, haemoglobin, into their cytoplasm.

Epithelial cells

Type: Skin and membranes

The cells that cover our bodies and line our body cavities form junctions with one another. Using proteins anchored between their membranes, the cells join forces to create strong barriers to protect the body.

Contractile cells

Type: Muscle

These cells contain a protein ratchet system, which enables them to contract. Actin and myosin form long strands, which slide past one another, pulling the edges of the cell together.

Nerve cells

Type: Brain and nerves

Nerve cells have specialised membranes, which use molecular pumps to maintain an electrochemical gradient; this allows them to transmit electrical signals. Nerves function more efficiently if they are insulated and many nerve cells are covered by a fatty sheath of myelin.

Stem cells

Type: Undifferentiated

Stem cells are ones that have not yet committed to a particular specialism. They are found in many locations and provide a replicating reservoir of cells that can be used to maintain and repair the body.

Extracellular matrix cells

Type: Connective tissue

The cells of the body are supported by networks of fibres including collagen and elastin. These are generated by extracellular matrix cells like fibroblasts, which produce and secrete precursor components that then assemble into the fibres that make up the matrix.

Endocrine cells

Type: Hormones

These cells generate hormones and release them locally or into the bloodstream. Their hormone-releasing activity is controlled by neurotransmitters sent from local nerves, or by other chemical messengers, which bind to receptors that are on the cell surface.

Germ cell

Type: Reproductive

Sperm and egg cells have just one copy of each chromosome and are formed by a special type of cell division called meiosis. When sperm and egg combine, the resulting cell has a full set of 46 chromosomes.

Muscle and movement

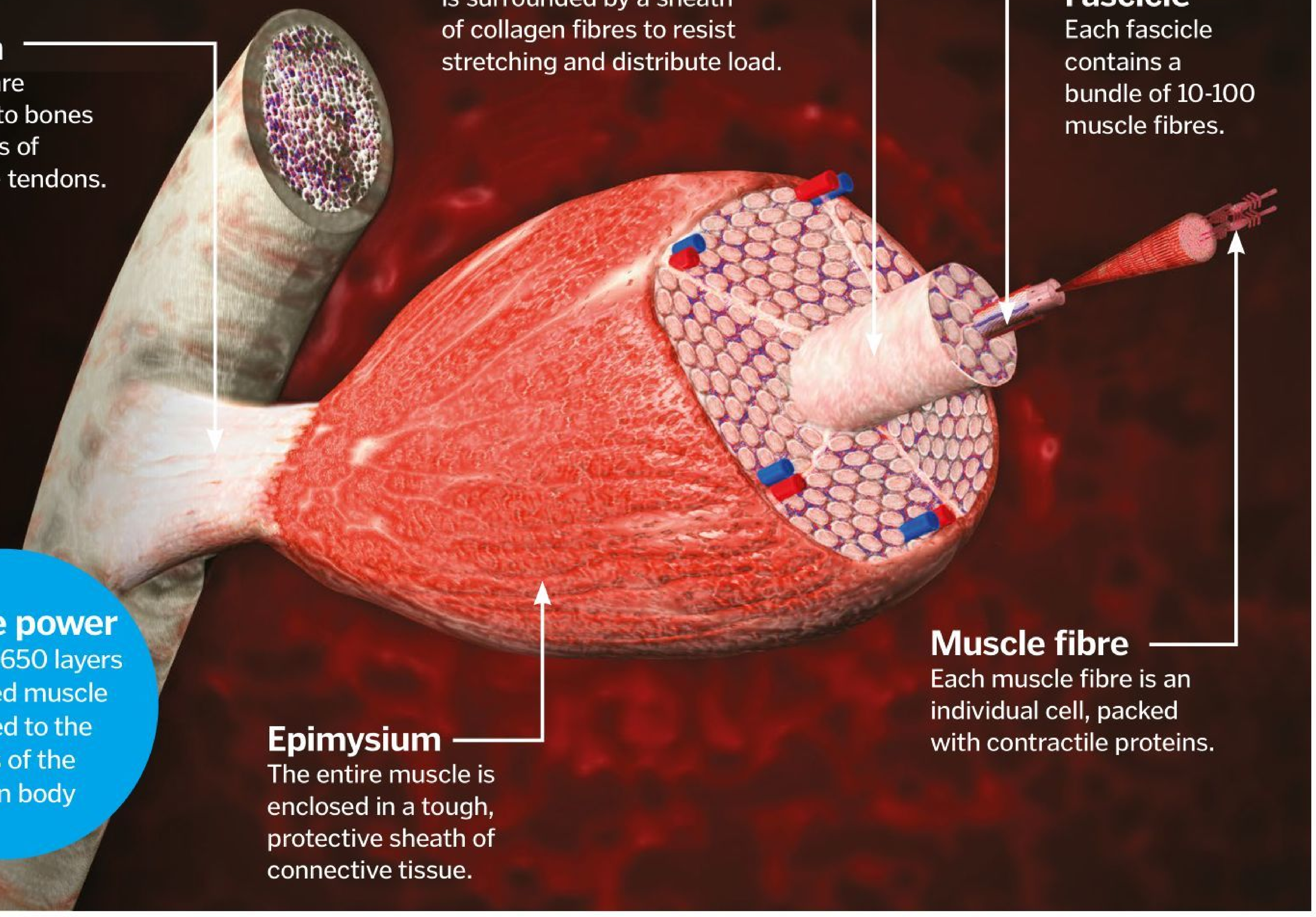
Skeletal muscle is responsible for moving the skeleton. It is composed of bundles of muscle fibres, sheathed in a strong collagen matrix, which extends into tendons that attach to the bone.

Within each muscle fibre is a molecular ratchet system made from the proteins actin and myosin. As the protein filaments slide past one another, the muscle fibre contracts lengthways and the fibre shortens.

Muscle fibres can be broadly categorised as being either 'fast twitch' or 'slow twitch'. Fast-twitch fibres use high-speed anaerobic respiration to produce rapid movements, but fatigue quickly.

In contrast, slow-twitch fibres use sustainable aerobic respiration and produce slower movement for longer periods of time.

The proportion of slow and fast-twitch fibres affects athletic performance, eg long-distance runners have a higher proportion of slow-twitch fibres than sprinters. Whether muscle fibres can change from one to another is under investigation.



Tendon
Muscles are attached to bones by bundles of collagen – tendons.

Connective tissue
Each layer within the muscle is surrounded by a sheath of collagen fibres to resist stretching and distribute load.

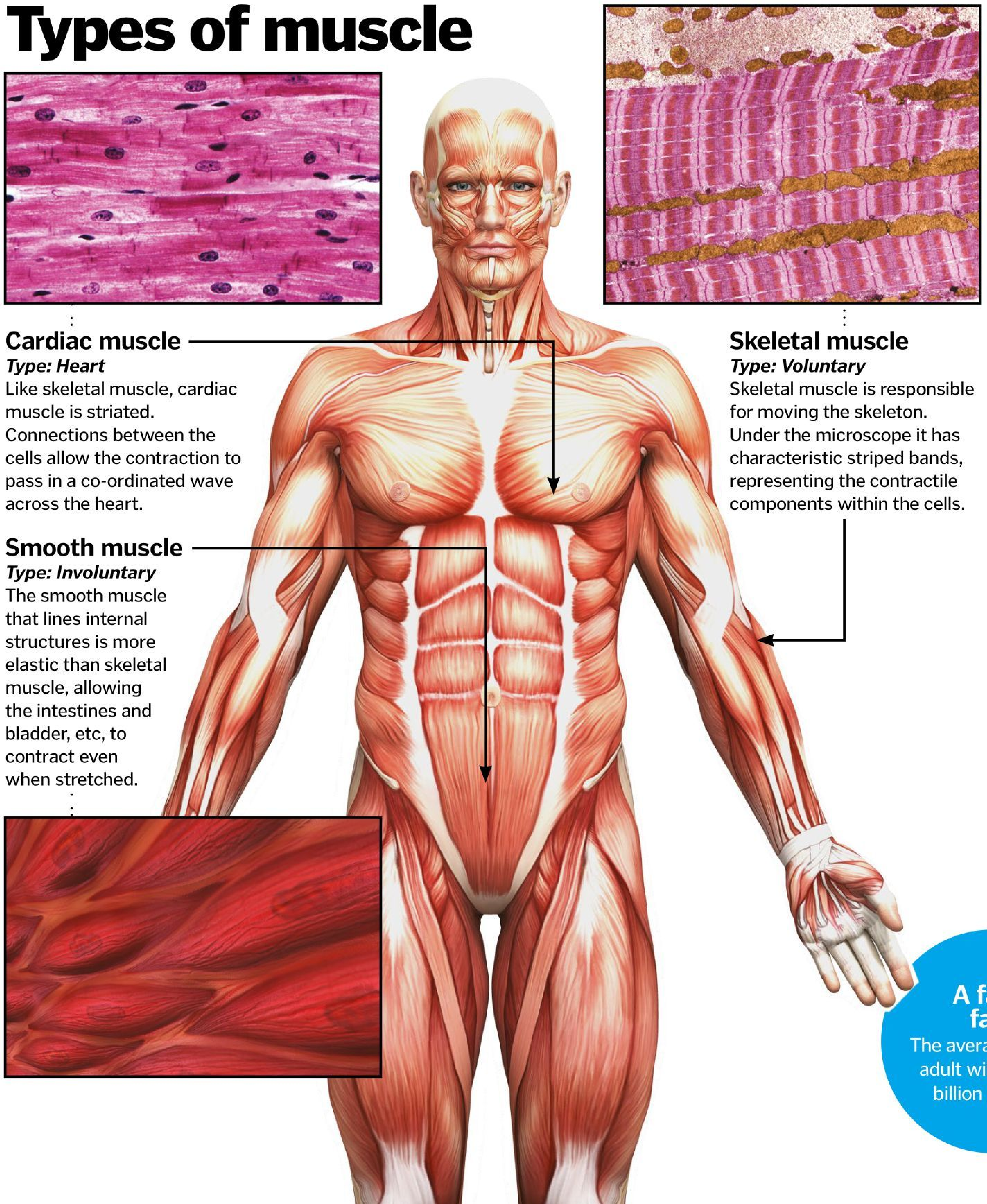
Fascicle
Each fascicle contains a bundle of 10-100 muscle fibres.

Muscle power
There are 650 layers of striated muscle attached to the bones of the human body

Epimysium
The entire muscle is enclosed in a tough, protective sheath of connective tissue.

Muscle fibre
Each muscle fibre is an individual cell, packed with contractile proteins.

Types of muscle



Cardiac muscle
Type: Heart
Like skeletal muscle, cardiac muscle is striated. Connections between the cells allow the contraction to pass in a co-ordinated wave across the heart.

Skeletal muscle
Type: Voluntary
Skeletal muscle is responsible for moving the skeleton. Under the microscope it has characteristic striped bands, representing the contractile components within the cells.

Smooth muscle
Type: Involuntary
The smooth muscle that lines internal structures is more elastic than skeletal muscle, allowing the intestines and bladder, etc, to contract even when stretched.

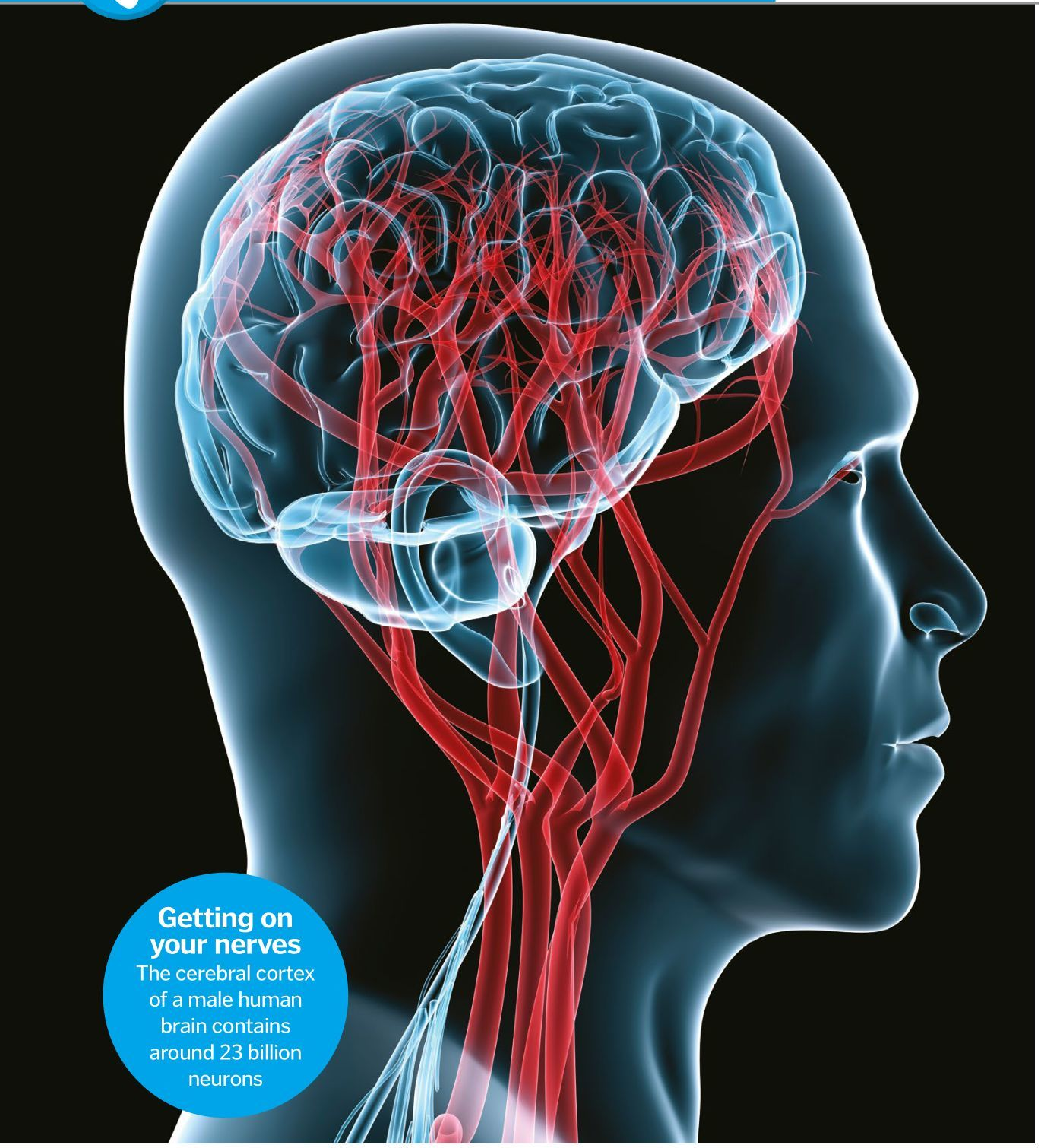
Why our bodies need a little fat

Adipose tissue provides the body with an energy reserve and also acts as a shock absorber – particularly on the soles of the feet. The fat cells – also known as adipocytes – contain a large lipid droplet, which takes up almost their entire volume, while their nuclei and other organelles are squashed on the perimeter.

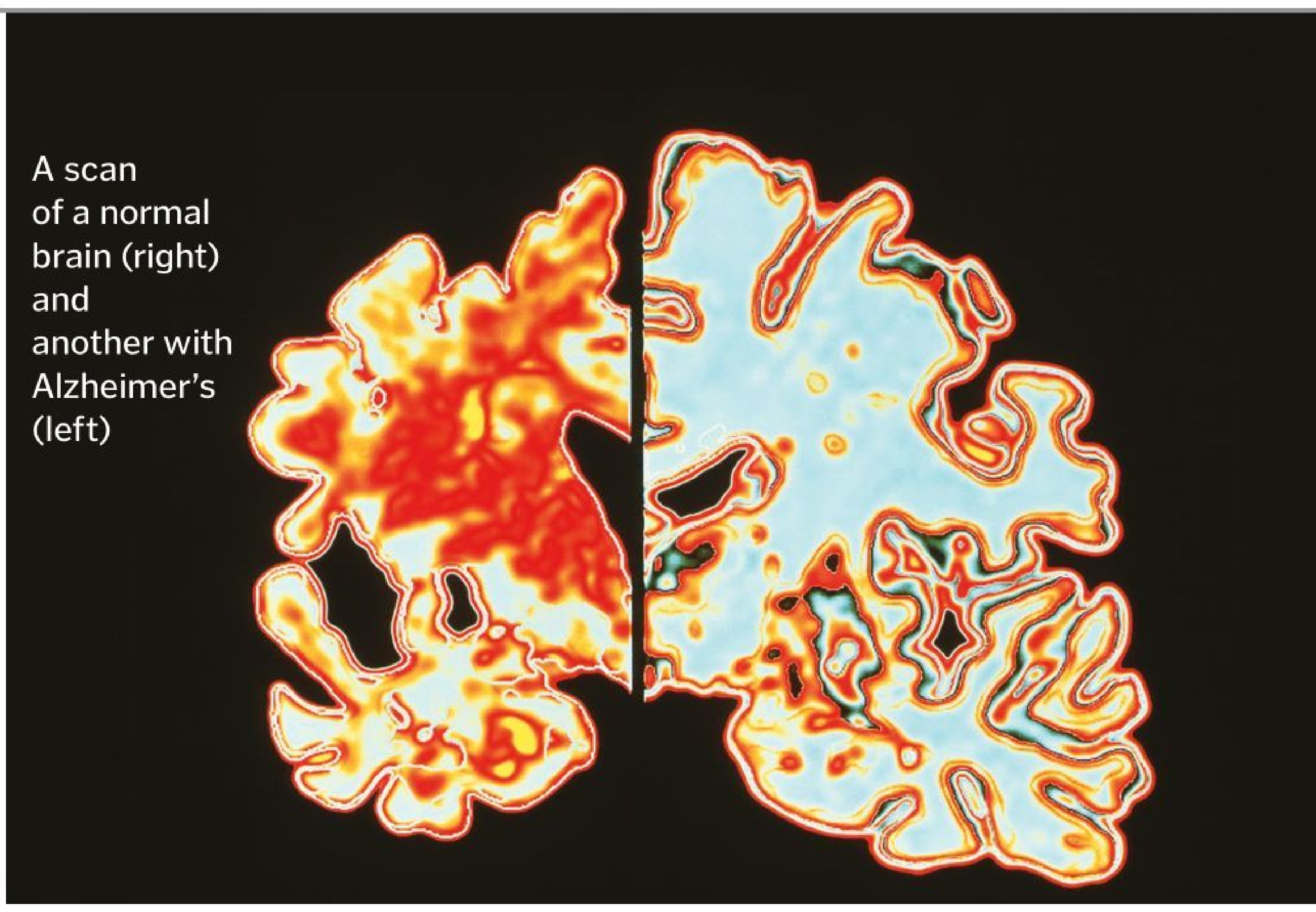
Adipocytes are not just used as storage sacks though; they have important metabolic and hormonal duties too, including involvement in the production of oestrogen.

Humans have a second type of fat tissue known as 'brown fat'. More commonly found in infants, brown fat provides a thermal blanket around the neck and the major blood vessels in the thorax. Brown fat cells are able to generate heat by a method known as uncoupling; instead of using glucose to make energy for the cell in the form of ATP, the brown fat can release the energy as heat. This is thought to be very important in newborns, who lack the ability to keep warm by shivering.

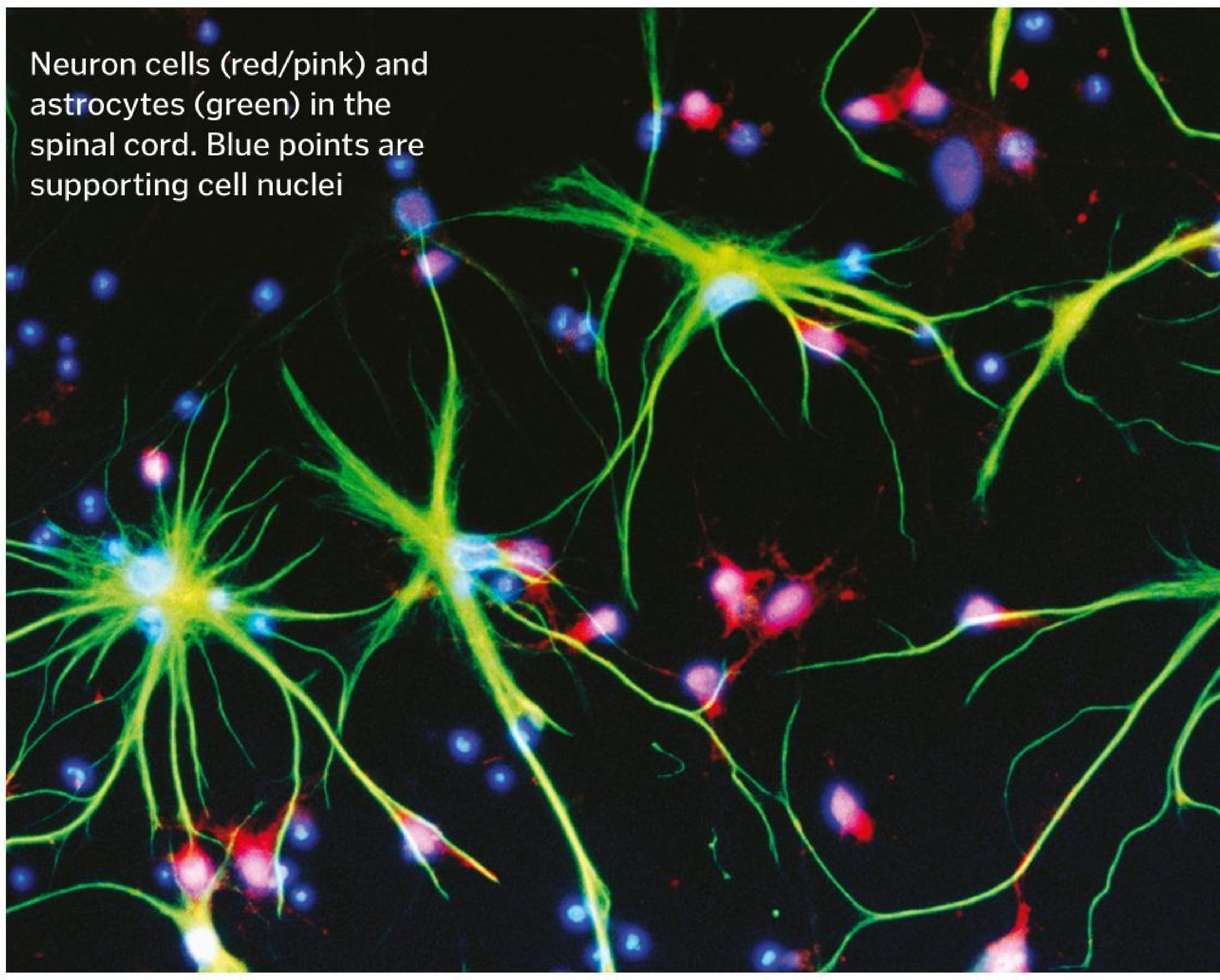
A fatty fact
The average human adult will have 30 billion fat cells



Getting on your nerves
The cerebral cortex of a male human brain contains around 23 billion neurons



A scan of a normal brain (right) and another with Alzheimer's (left)



Neuron cells (red/pink) and astrocytes (green) in the spinal cord. Blue points are supporting cell nuclei

Inside the brain

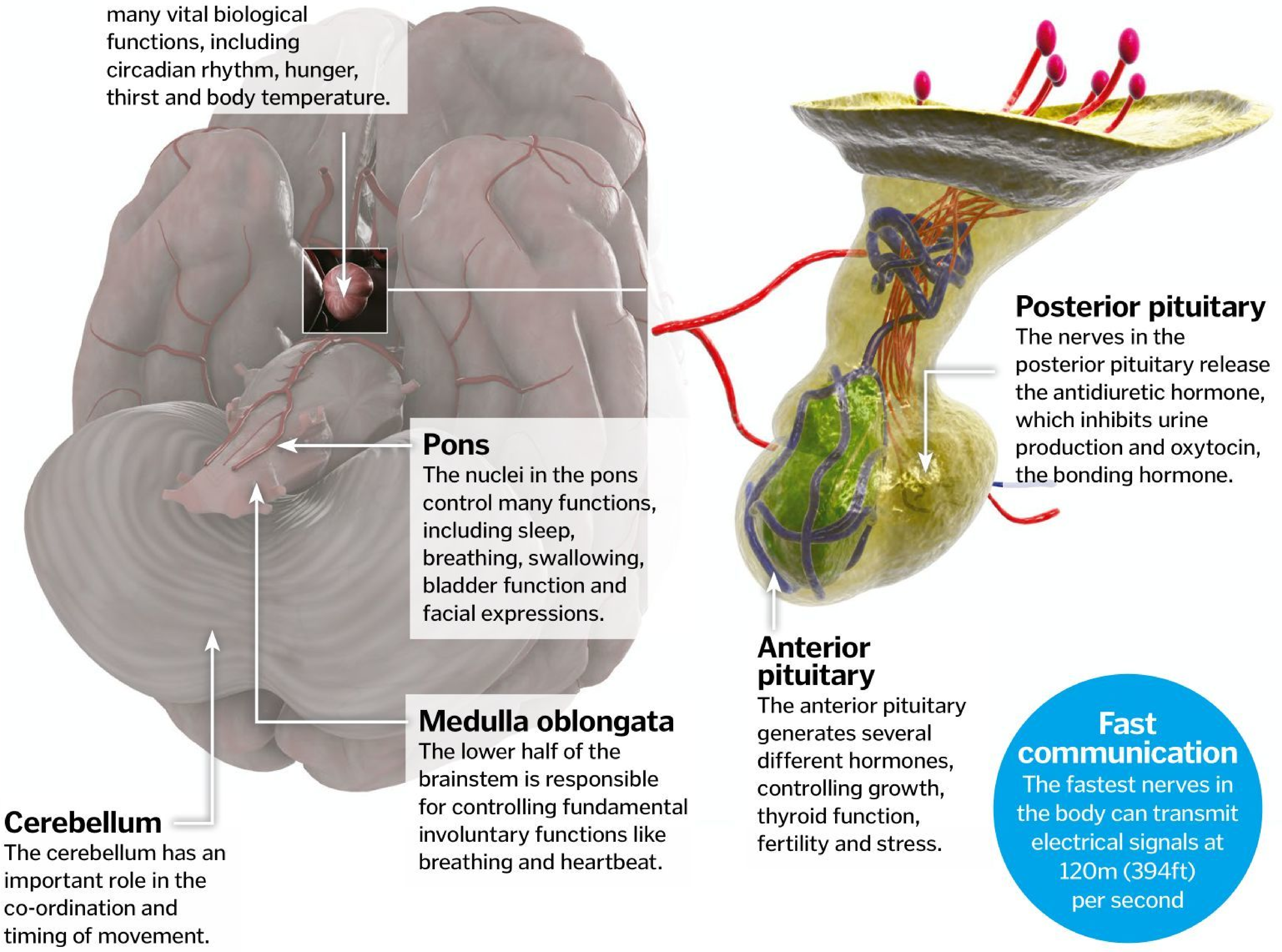
The brain is made up of two major types of cells: neurons and glial cells.

The neurons of the brain are highly specialised cells, interconnected by long, branching processes. They communicate through electrical 'action potentials', which can travel along the axons at speeds of 1-100 metres (3.3-328 feet) per second.

When an action potential reaches the synapse at the end of a nerve, it triggers the release of chemical transmitters, which bind to receptors on neighbouring nerves. Depending on the combination of neurotransmitters released – and the timing – the target nerve will fire, propagating the signal through the brain.

Glial cells, on the other hand, provide support to the neurons and have a variety of specialist functions. Astrocytes help to take up excess neurotransmitters from synapses, preventing neurons from damage due to excessive stimulation, while oligodendrocytes form fatty sheaths in order to insulate nerve cells in the brain and spinal cord.

The brain has significantly more protection than the other organs of the body. It is shielded from mechanical stress by the thick bones of the skull and is suspended in a cushion of cerebrospinal fluid. At the microscopic level, the brain is protected from potential hazards in the bloodstream by the blood-brain barrier – the cells lining the capillaries are joined together by tight junctions, controlling the passage of all molecules and bacteria into the organ.



Hypothalamus
The hypothalamus controls many vital biological functions, including circadian rhythm, hunger, thirst and body temperature.

Pons
The nuclei in the pons control many functions, including sleep, breathing, swallowing, bladder function and facial expressions.

Medulla oblongata
The lower half of the brainstem is responsible for controlling fundamental involuntary functions like breathing and heartbeat.

Cerebellum
The cerebellum has an important role in the co-ordination and timing of movement.

Posterior pituitary
The nerves in the posterior pituitary release the antidiuretic hormone, which inhibits urine production and oxytocin, the bonding hormone.

Anterior pituitary
The anterior pituitary generates several different hormones, controlling growth, thyroid function, fertility and stress.

Fast communication
The fastest nerves in the body can transmit electrical signals at 120m (394ft) per second

DID YOU KNOW? *The red colour of blood isn't due to iron, but the shape of the porphyrin molecule that contains it*

What role do hormones play in the body?

Angiotensin	*Produced: Liver*	Angiotensin causes blood vessels to constrict, raising blood pressure. ACE inhibitors that treat high blood pressure inhibit its activity.
Erythropoietin	*Produced: Kidney*	Cells in the kidney are sensitive to blood oxygen levels and can release this hormone to encourage production of new red blood cells.
Ghrelin	*Produced: Stomach*	A chemical signal produced mainly by the stomach. It acts as an appetite stimulant, making you feel both hungry or full up.
Oxytocin	*Produced: Mainly in the brain*	This is also known as the 'bonding hormone' and is produced at high levels during and after childbirth.
Cortisol	*Produced: Adrenal glands*	The 'stress hormone' helps to increase blood sugar by promoting the breakdown of fat and muscle tissue.
Leptin	*Produced: Fat*	Made by fat tissue, leptin plays a fundamental role in acting as a fuel gauge and telling the brain just how much fat is stored in the body.

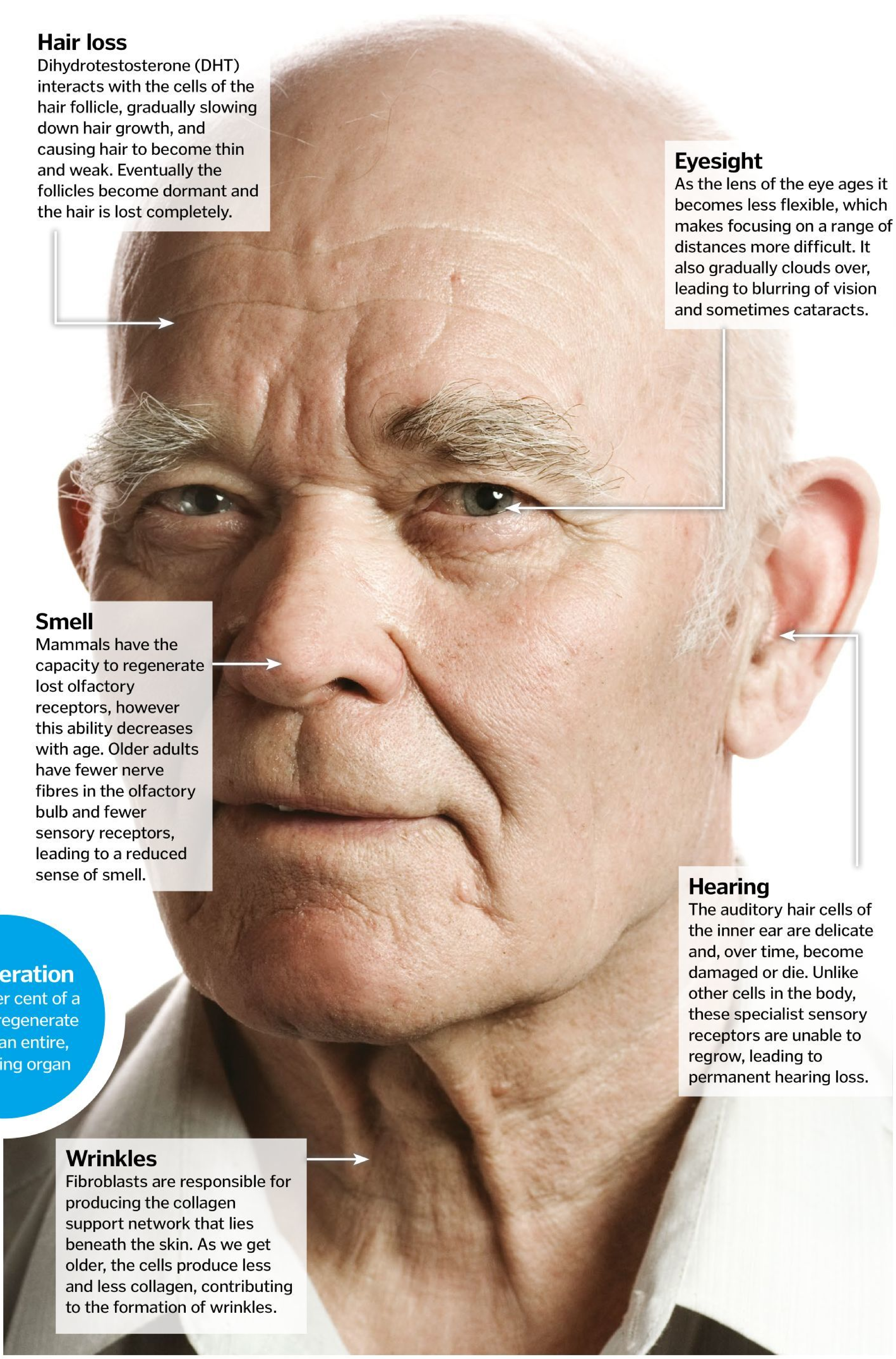
The ageing body

The human body changes as it ages and the peak time for organ functionality is thought to be around the age of 30. The body has amazing capacity for regeneration, but cells can only divide a finite number of times, and as we get older our ability to repair damaged tissue decreases.

Dramatic changes, such as the menopause, produce obvious effects on the body. Female sex hormones are not just involved in reproduction, but also play a role in other processes, such as the maintenance of bone density. In the absence of oestrogen, bone mineral density decreases, which can lead to osteoporosis. A similar, but less dramatic, effect can be seen in men as testosterone levels begin to drop.

Similar decline in functionality can be observed throughout the human body; collagen in the skin begins to decrease, insulated axons in the brain shorten, and DNA damage accumulates, leading to an ever greater risk of cancer.

However, it's not all bad. Life expectancy is on the increase, and scientists are coming closer to understanding – and being able to slow – the complex processes of human ageing.



Hair loss
Dihydrotestosterone (DHT) interacts with the cells of the hair follicle, gradually slowing down hair growth, and causing hair to become thin and weak. Eventually the follicles become dormant and the hair is lost completely.

Eyesight
As the lens of the eye ages it becomes less flexible, which makes focusing on a range of distances more difficult. It also gradually clouds over, leading to blurring of vision and sometimes cataracts.

Smell
Mammals have the capacity to regenerate lost olfactory receptors, however this ability decreases with age. Older adults have fewer nerve fibres in the olfactory bulb and fewer sensory receptors, leading to a reduced sense of smell.

Hearing
The auditory hair cells of the inner ear are delicate and, over time, become damaged or die. Unlike other cells in the body, these specialist sensory receptors are unable to regrow, leading to permanent hearing loss.

Wrinkles
Fibroblasts are responsible for producing the collagen support network that lies beneath the skin. As we get older, the cells produce less and less collagen, contributing to the formation of wrinkles.

As the body gets older it becomes more susceptible to faulty cells that cause cancer

Arthritis is the main cause of disability in over-55s in industrialised countries

Regeneration
Just 25 per cent of a liver can regenerate to form an entire, functioning organ

© Alamy; Corbis; Getty; Thinkstock

YOUR FIRST YEAR

What happens to the human body in the first 12 months of life

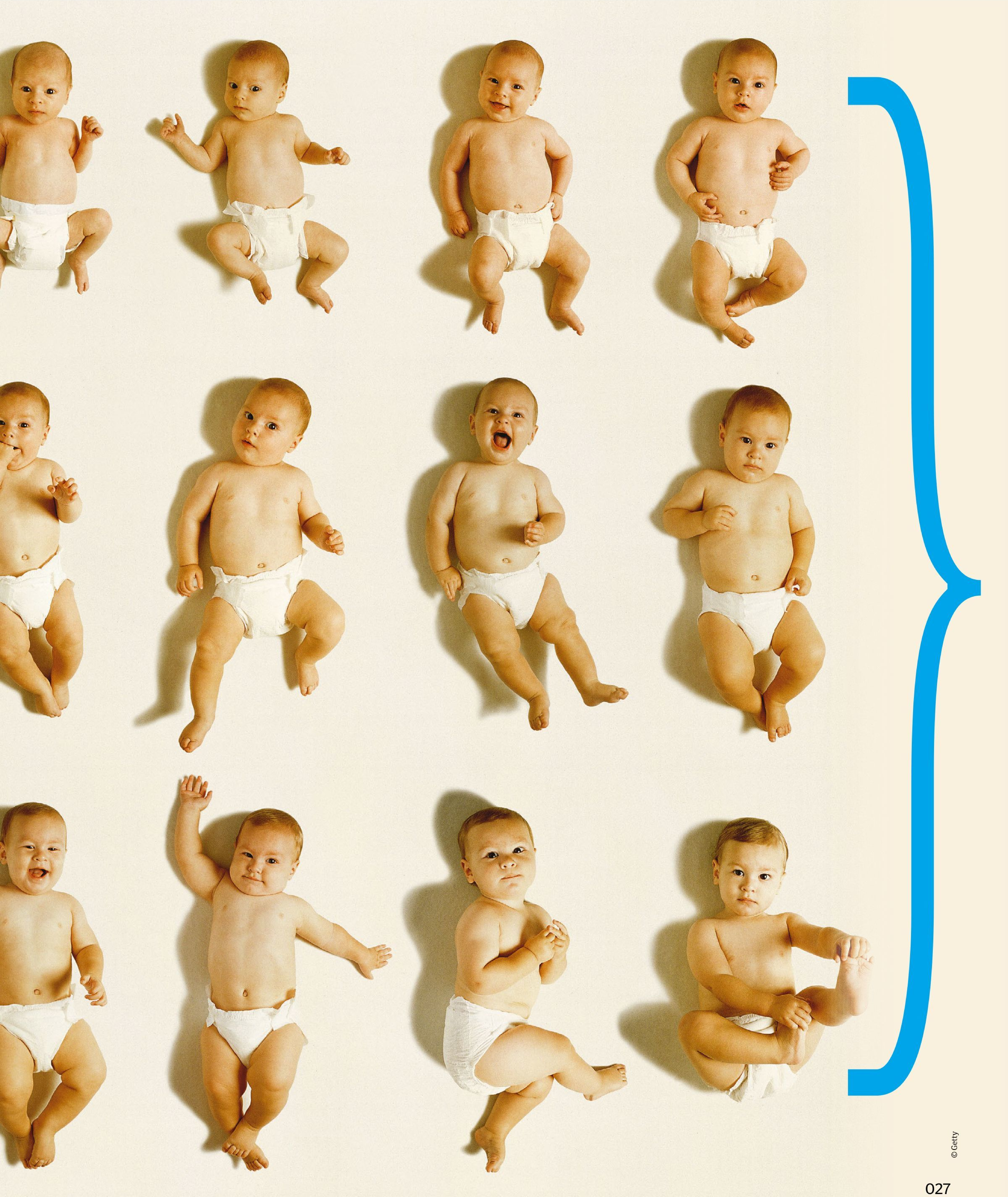
We are born well before we're ready to fend for ourselves, but we learn faster in our first three years than we will for the rest of our lives. So how do we get from vulnerable newborns unable to lift our own heads to walking, talking toddlers?

BIRTH

Babies enter the world with a lot of growing left to do. From around 35 weeks of pregnancy babies start becoming cramped. As the foetus gets bigger it demands more and more energy, and there's only so much that the mother can supply. Before they are born, their growth starts to slow.

Entering the world for the first time is a shock to a baby's system, and the first days of life are critical. Until the moment they emerge from the womb, their mother's body has supported every one of their needs. She maintains a constant temperature, digests food to supply nutrients and breathes to supply oxygen. She also deals with waste and fends off infection. Then suddenly the baby has to fend for itself.

As it hits the cold air of the delivery room, a powerful inward breath pulls its lungs open and fills them with air. In the safety of the womb, all the oxygen the baby needed came from the umbilical cord. The lungs were full of amniotic fluid and the heart diverted blood past them through a hole called the foramen ovale and a tube called the ductus arteriosus. Suddenly the baby needs to breathe. The hole in the heart slams shut and blood rushes into the lungs. Within hours or days after birth the tube, and another that carried blood from the umbilical cord to the heart (ductus venosus), closes too.



© Getty

The other organ systems also spring into action. The baby has been practising breathing and swallowing in the womb, and the kidneys have already started working. Within 24 hours the gut starts moving, passing a dark green or black, tarry substance called meconium. It contains bile, mucus, amniotic fluid and anything else the baby has ingested in utero. Once this fluid is out of the way milk digestion can begin.

The newborn stomach is tiny — barely the size of a marble — so the baby needs to wake every few hours to feed. It can only take a few small mouthfuls at a time. The mother produces a thick, golden-yellow breast milk called colostrum. It's packed with energy but is lower in fat than normal breast milk, which newborns can find hard to digest. Instead, it's full of protein — perfect for a growing baby.

> "Babies are born with vital reflexes built in"

Colostrum has a mild laxative effect, which helps to get the baby's gut moving, and it comes with a secret weapon: antibodies. These neutralise bacteria and viruses, sticking them together and triggering their destruction. Throughout pregnancy they cross from mother to baby via the placenta, but this type of immunity is only temporary. The baby will be able to make its own, but this takes a few months. In the meantime, colostrum provides a boost, helping to stave off infection.

The newborn has some tricks of its own to help it survive this vulnerable time. Though they have a lot to learn, babies are born with some vital reflexes built in. These include simple things like blinking, swallowing and yawning, along with more complicated responses.

The rooting reflex makes the baby turn their head or open their mouth when something touches their cheek or lip, and the suck reflex makes them suck if something touches the roof of their mouth. These instincts help with feeding.

Then there are the Moro reflex and the palmar grasp reflex. The first happens when a baby feels as if they are falling. They extend their arms and legs and arch their backs before curling up. The second makes the fingers and toes curl if you touch the palm of their hand or the soles of their feet. Together they help the baby to survive.

FIRST WEEKS

Brand new babies can hear and respond to noises and are born with the beginnings of communication. They will turn their head towards light and sound, make out the face of the person holding them and cry when they are in need. It only takes a few weeks for these skills to start to improve. They rapidly start to recognise the voice of their mother, and soon they begin to make different noises, cooing and gurgling as well as crying.

For the first few weeks babies can only focus on objects right in front of their faces, and their eyes frequently cross. At this stage their hand-eye coordination is poor. Very young babies will investigate their own hands and fingers, but they can't yet use them properly, and they often keep their hands in fists.

Inside, their bodies are undergoing rapid change fuelled by milk. If the baby is being breastfed, normal breast milk has now replaced colostrum. It's higher in fat and contains enzymes that help the digestive system to access the nutrients. It's also packed with sugars. Not only do these provide energy, they also help friendly bacteria to colonise the large intestine.

Babies are ready to try their first meal at around six months old

Why do babies sleep so much?

Brand new infants spend around 16 hours a day in the land of nod. At first they wake often to feed, but by the time they are 12 weeks old and weigh on average 5.7 kilograms they begin to sleep for longer periods.

Like adults, babies cycle through four sleep stages. They begin with the lightest dozing before a gradual drop into the deepest slumber, and this rhythm starts when they are still in the womb. Between these cycles they go through phases of rapid eye movement (REM) sleep, spending up to half of their sleep time dreaming.

Early work suggests that sleep is important for consolidating learning and for brain plasticity. In other words, it helps with the strengthening and pruning of connections between different nerve pathways in the brain. Some studies suggest that inadequate sleep may cause problems in the refinement of nerve connections. However, it's still early days and scientists need to do more research to confirm these findings.

TWO MONTHS OLD

Babies spend much of their time eating and sleeping, and their bodies start to grow rapidly. In the womb, cells divide constantly to form tissues and organs, but after birth growth shifts. Rather than making new cells, babies increase the size of the cells they already have.

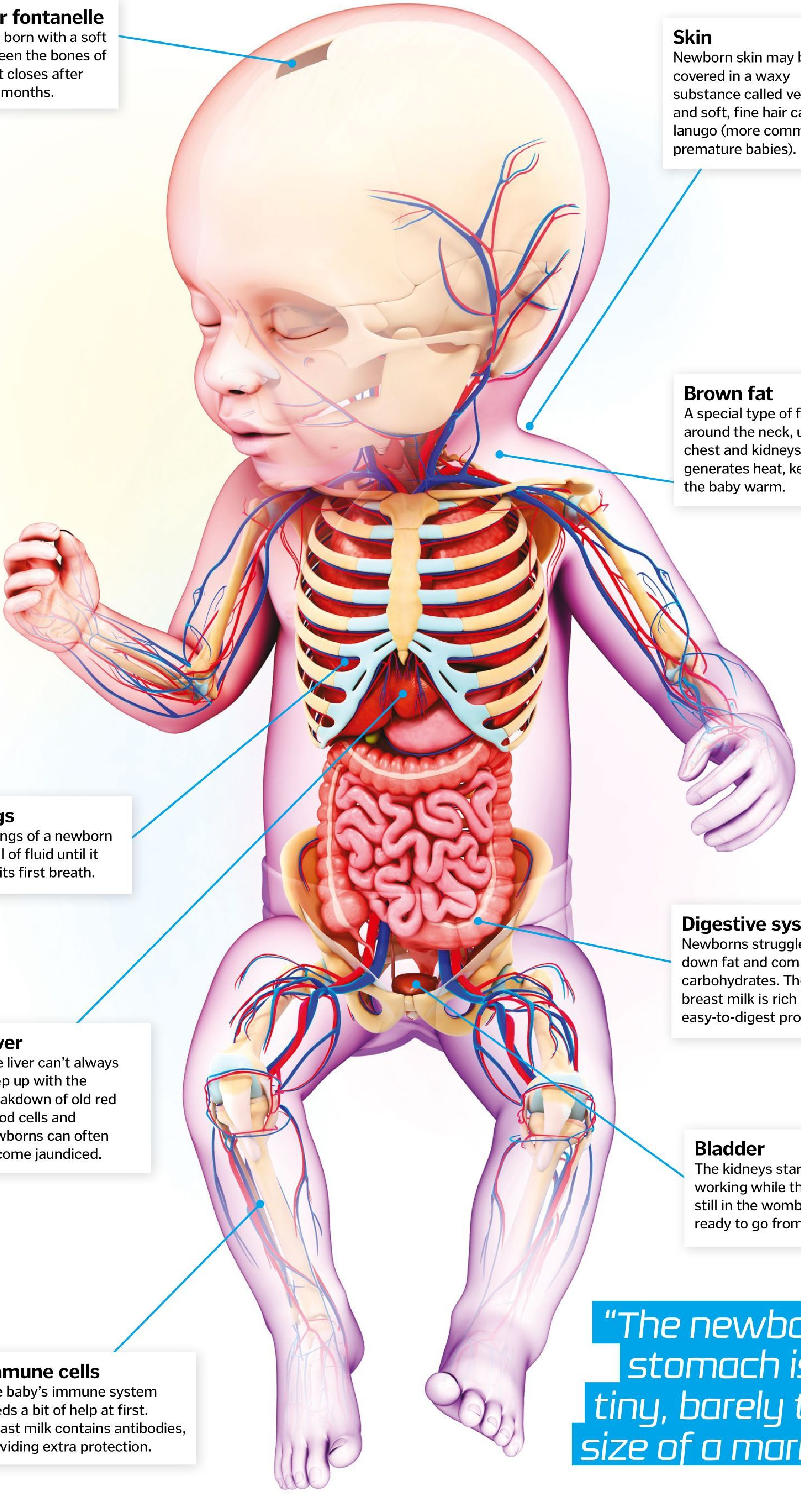
The tissues of newborn babies are very different to those of children and adults. There is more fluid around their muscle and nerve cells, and they have less cytoplasm inside. As the baby develops this balance shifts. Muscle cells expand, filling with cytoplasm and molecules involved in contraction. Nerve cells extend, strengthening connections and making new ones, and the amount of fluid outside these cells starts to fall. With newfound strength, babies learn to push up with their hands when placed on their tummies and start to hold their head a little steadier, their movements becoming less jerky and more coordinated.

Fat continues to quickly build up under the skin, helping to keep the infant warm. By the

DID YOU KNOW? *The average length of a full-term newborn is 50–51cm. By their first birthday, they've grown by 25cm*

BABY ANATOMY

Babies are more than just miniature adults — they have their own unique anatomy



Anterior fontanelle
Babies are born with a soft spot between the bones of the skull. It closes after around 18 months.

Skin
Newborn skin may be covered in a waxy substance called vernix and soft, fine hair called lanugo (more common in premature babies).

Brown fat
A special type of fat around the neck, upper chest and kidneys generates heat, keeping the baby warm.

Lungs
The lungs of a newborn are full of fluid until it takes its first breath.

Digestive system
Newborns struggle to break down fat and complex carbohydrates. The first breast milk is rich in easy-to-digest proteins.

Liver
The liver can't always keep up with the breakdown of old red blood cells and newborns can often become jaundiced.

Bladder
The kidneys start working while the baby is still in the womb and are ready to go from birth.

Immune cells
The baby's immune system needs a bit of help at first. Breast milk contains antibodies, providing extra protection.

> "The newborn stomach is tiny, barely the size of a marble"

© SPL; Thinkstock

two month mark babies are already starting to develop social skills. They begin to follow things with their eyes and recognise people at a distance, and they begin to smile and laugh.

HALFWAY THROUGH

Babies can finally hold their heads steady at around 16 weeks of age. They will also start to push down with their legs if they're held above a hard surface, and by six months they can roll over, push up to a crawling position and even stand with support.

At around this time babies also begin to use their hands and eyes together. They reach for objects and rake with their fingers to grab them, and they start to use their mouths to explore objects further. With all this extra strength and coordination, the grasp and Moro reflexes are no longer needed. These early fail-safes fade away. Babies start to learn to pass toys from one hand to the other.

Their eyesight improves too. By this stage they are becoming more perceptive to the subtleties of different colours, and they start to copy facial movements. They recognise and express emotion and begin to find their voice. They blow raspberries and start to make consonant sounds like 'ba', 'da' and 'ga', using noise to get attention and to express themselves. They will also start to recognise words, especially their own name.

> "To fuel all this progress, six-month-old infants often switch to solid food"

To fuel all this progress, six-month-old infants often switch to solid food. As the baby grows, the fat content of breast milk has been increasing from about 2g/dL of colostrum (grams per decilitre, equivalent to 100 millilitres) to 4.9g/dL. It has provided energy and contributed to a growing store of fat under the skin. But now the digestive system is ready for more.

A newborn's digestive organs are not only smaller than an adult's, but they also work differently. They make different quantities of enzymes and bile and they operate at a different pH. But at six months old things are starting to change. The first teeth come through, starting with the bottom front teeth then the top. Swallowing improves and the digestive system will start to produce enzymes to break down complicated meals.

FIRST BIRTHDAY

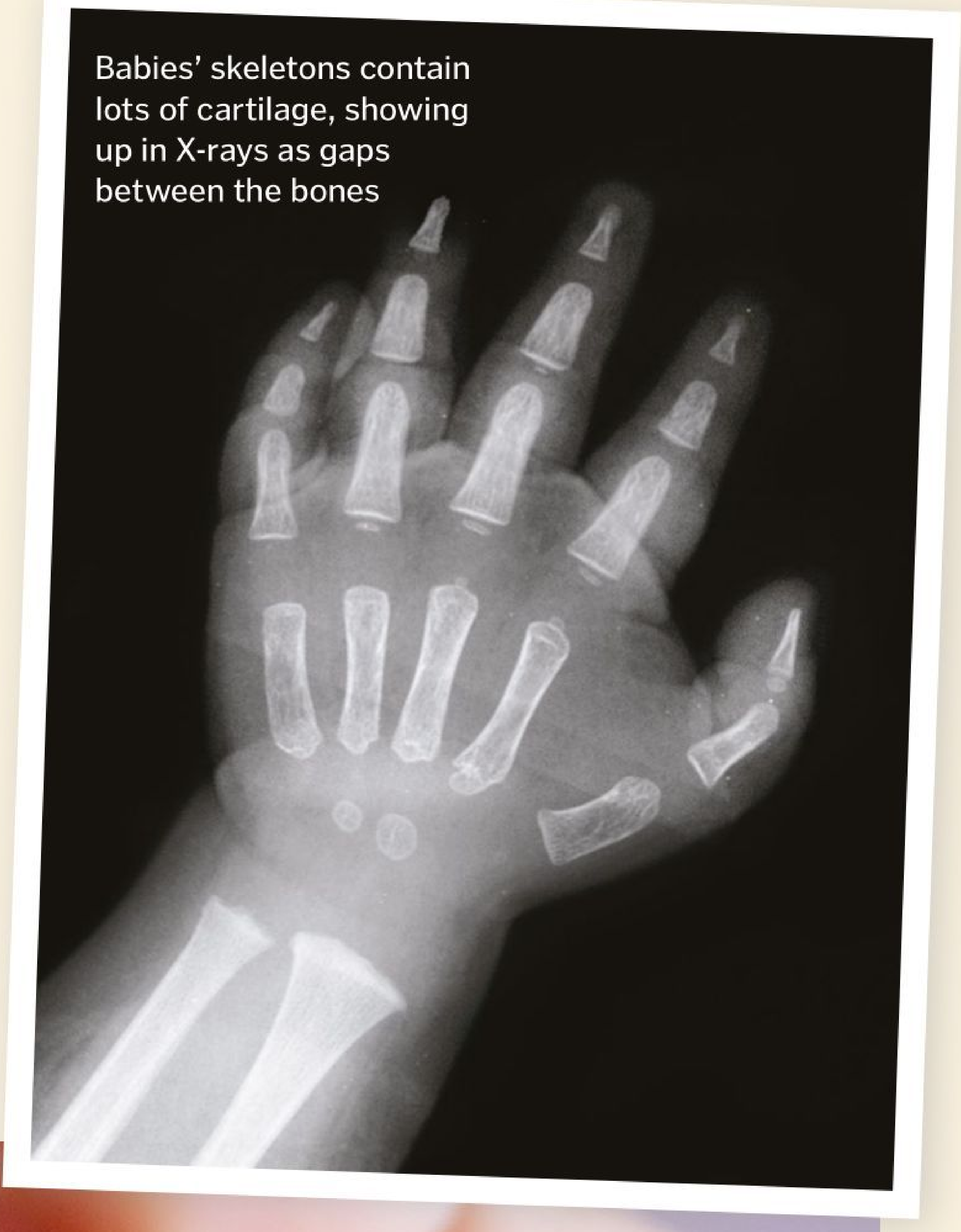
By their first birthday, babies are starting to develop complex behaviours. They have favourite things and favourite people. They start to understand 'object permanence' — the idea that objects and people exist even though you can't always see them. They look for hidden objects and they begin to grasp the effects of gravity by learning to drop things and watching how they fall to the ground.

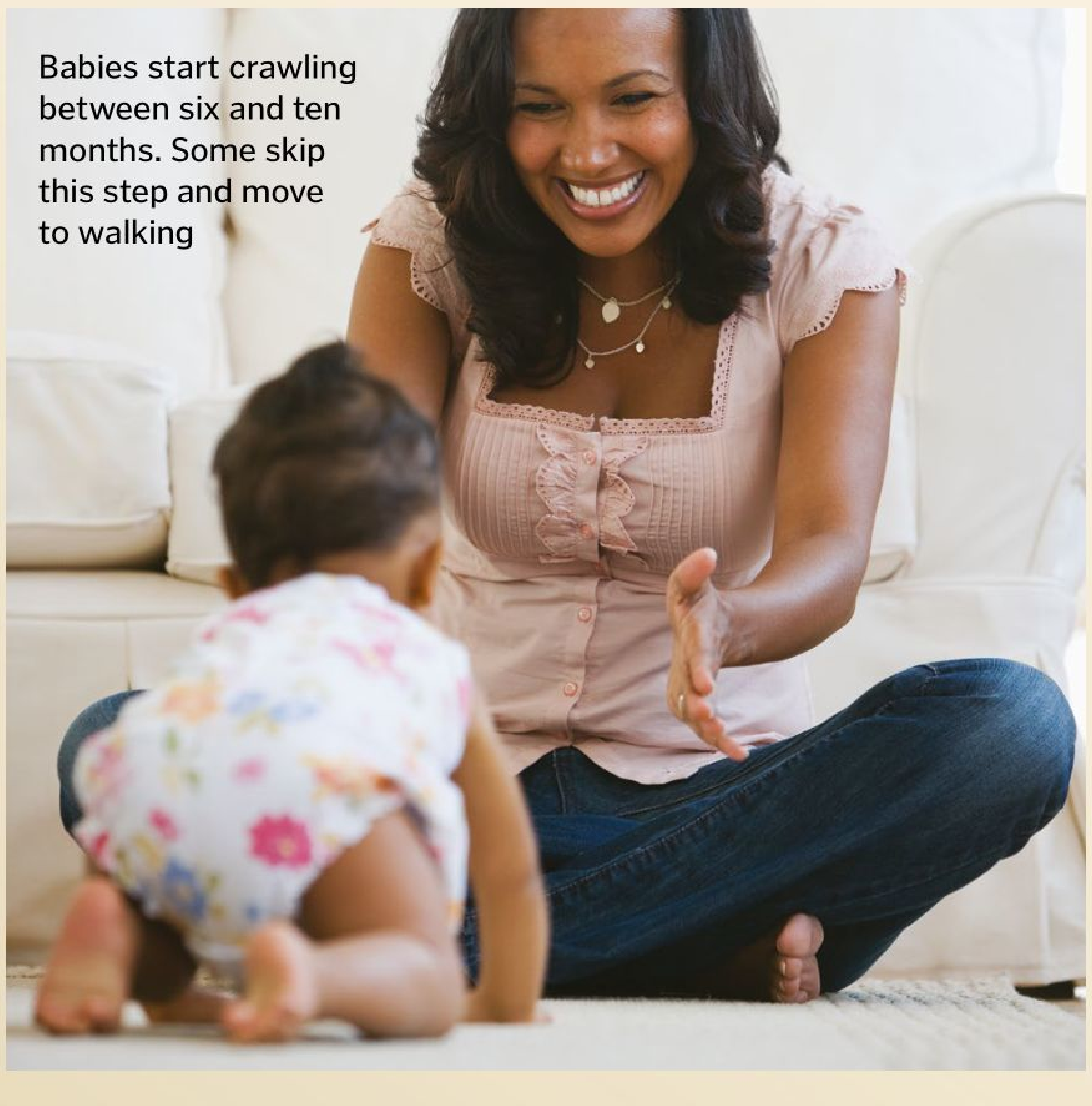
They also begin to respond to requests and make demands of their own. They will copy and use gestures like waving, pointing and head shaking. By now they will also understand familiar words and follow simple directions, as well as being able to help with tasks like dressing. Most importantly of all, they will start to communicate using 'babble'.

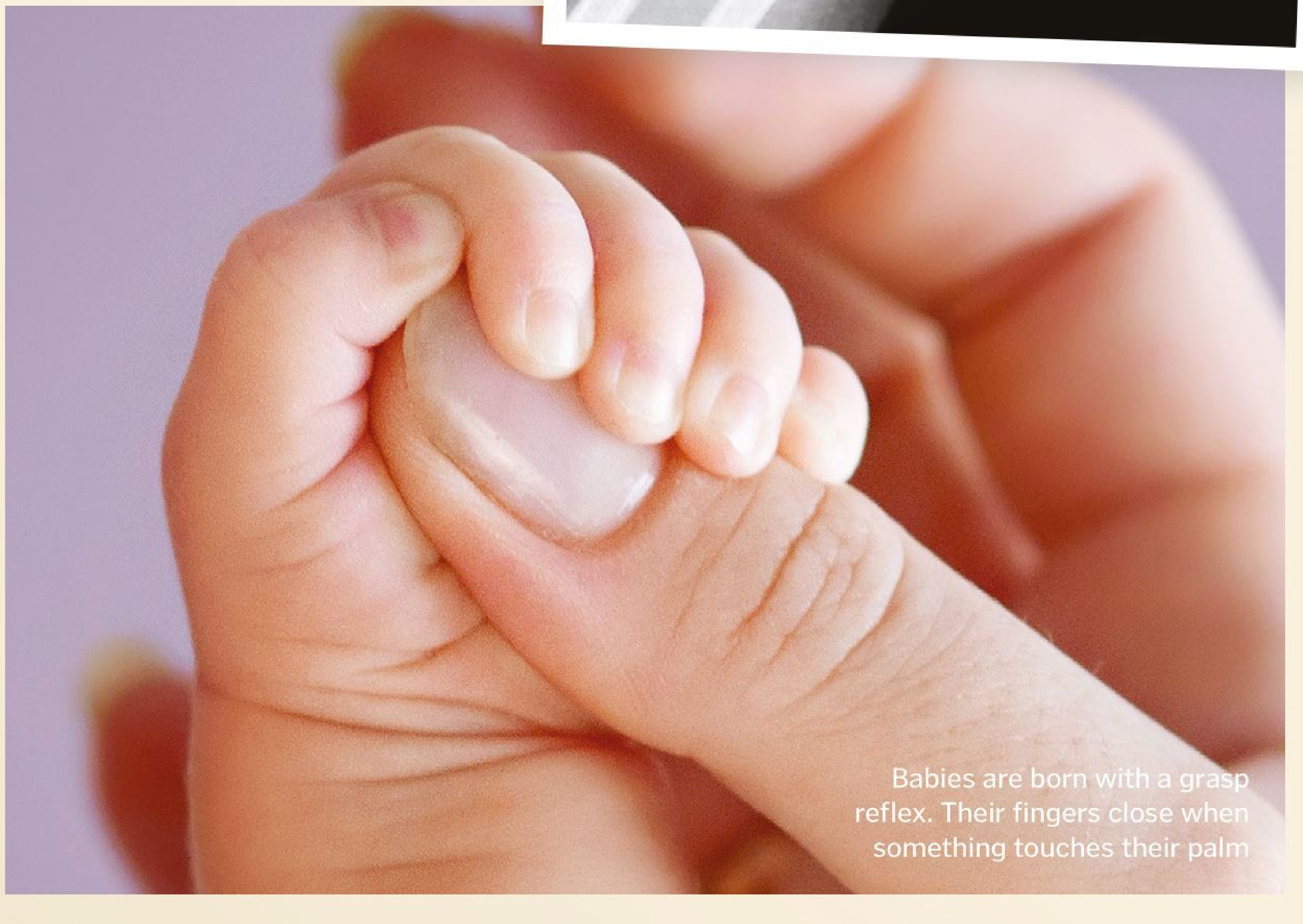
Their coordination has by now improved too. The grasp reflex is long gone, and they can move objects easily from one hand to the other. They can pick up small things between their thumb and forefinger and they will test new objects by shaking and banging. They will begin cruising, holding on to objects and moving around on two legs. Some may even take their first steps.

The hole that shunted blood through the heart when they were born is now fully healed over. Back teeth are starting to come through and the digestive system is processing full meals. The lungs have more air sacs, increasing surface area for gas exchange, and the brain has developed billions upon billions of new connections.

Over the coming months, babies transform into toddlers. As they begin to develop their understanding of the world, they start wanting to be more independent. They learn to walk, they start to talk and they even play games. Human babies are born tiny and vulnerable, but in a few short months they are already well on the way to growing up.


Babies' skeletons contain lots of cartilage, showing up in X-rays as gaps between the bones

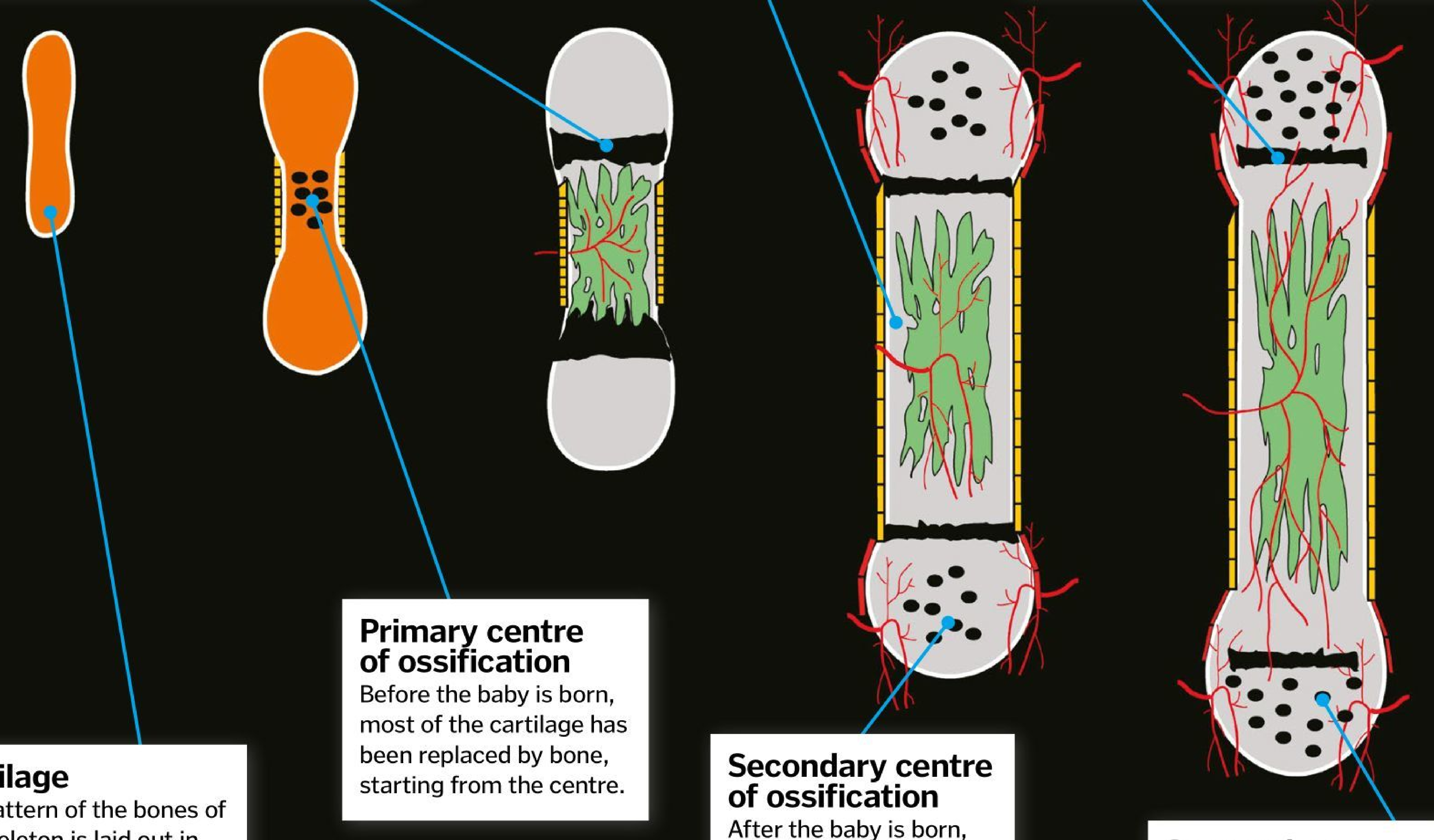

Babies start crawling between six and ten months. Some skip this step and move to walking


Babies are born with a grasp reflex. Their fingers close when something touches their palm

DID YOU KNOW? *Baby boys gain around 6kg in weight in their first year. Girls, on the other hand, gain around 5.5kg in weight*

BRAIN DEVELOPMENT / HOW BONES GROW

Skeletons start out as cartilage and gradually turn to bone



Calcified cartilage
Calcium salts are deposited in the cartilage, causing it to harden, and blood vessels penetrate the cartilage.

Compact bone
A tube of compact bone forms around the middle and the cartilage inside breaks down.

Growth plates
Cartilage continues to form at the growth plates, gradually lengthening the bones until maturity (which is around 18 years old).

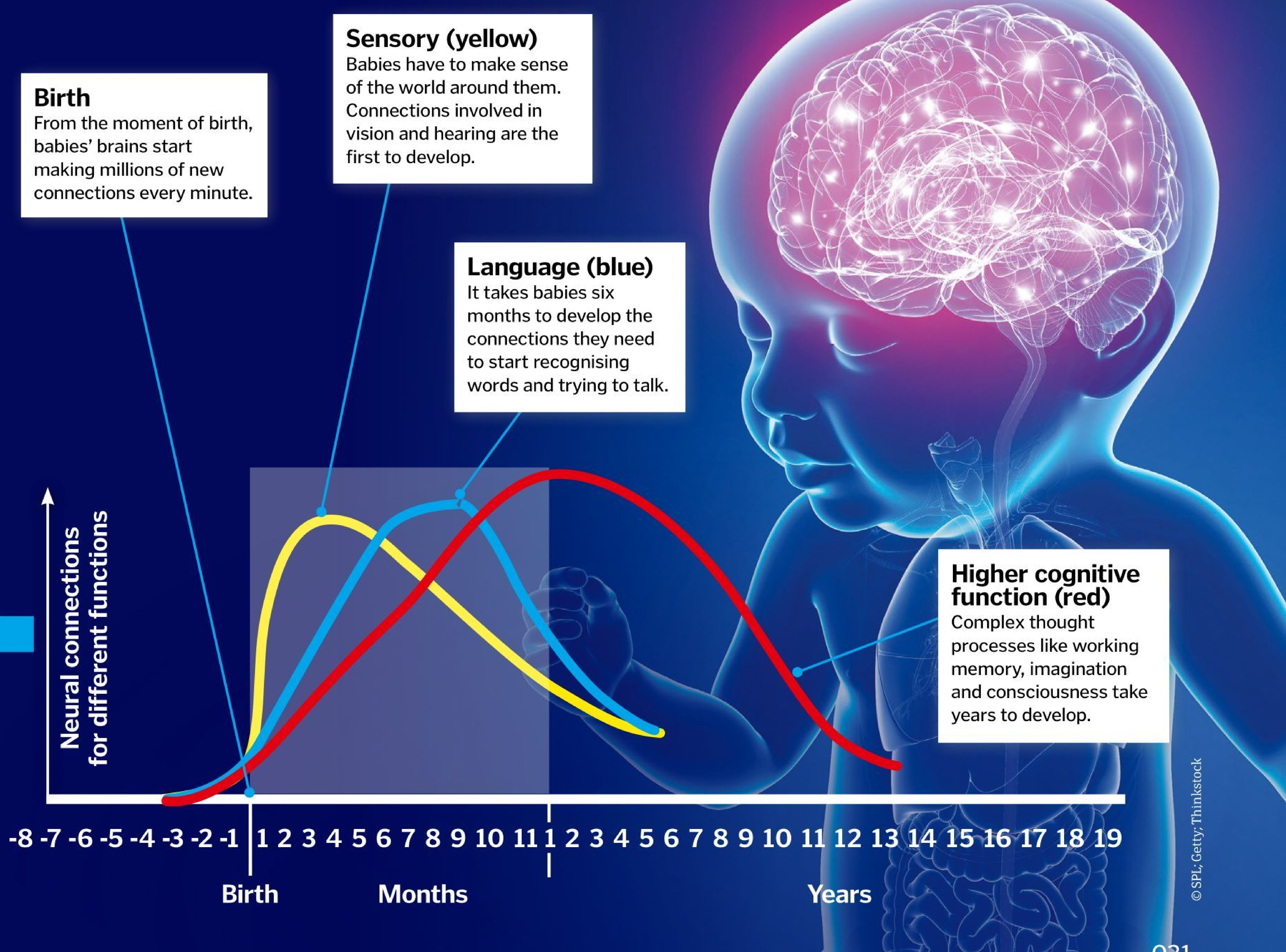
Cartilage
The pattern of the bones of the skeleton is laid out in cartilage by around the eighth week of pregnancy.

Primary centre of ossification
Before the baby is born, most of the cartilage has been replaced by bone, starting from the centre.

Secondary centre of ossification
After the baby is born, most of the the remaining cartilage at either end starts to be replaced by bone.

Spongy bone
The ends of the bone are spongy in structure, with plates and cavities.

Newborn brains grow from 25 to 90 per cent of adult volume in just five years



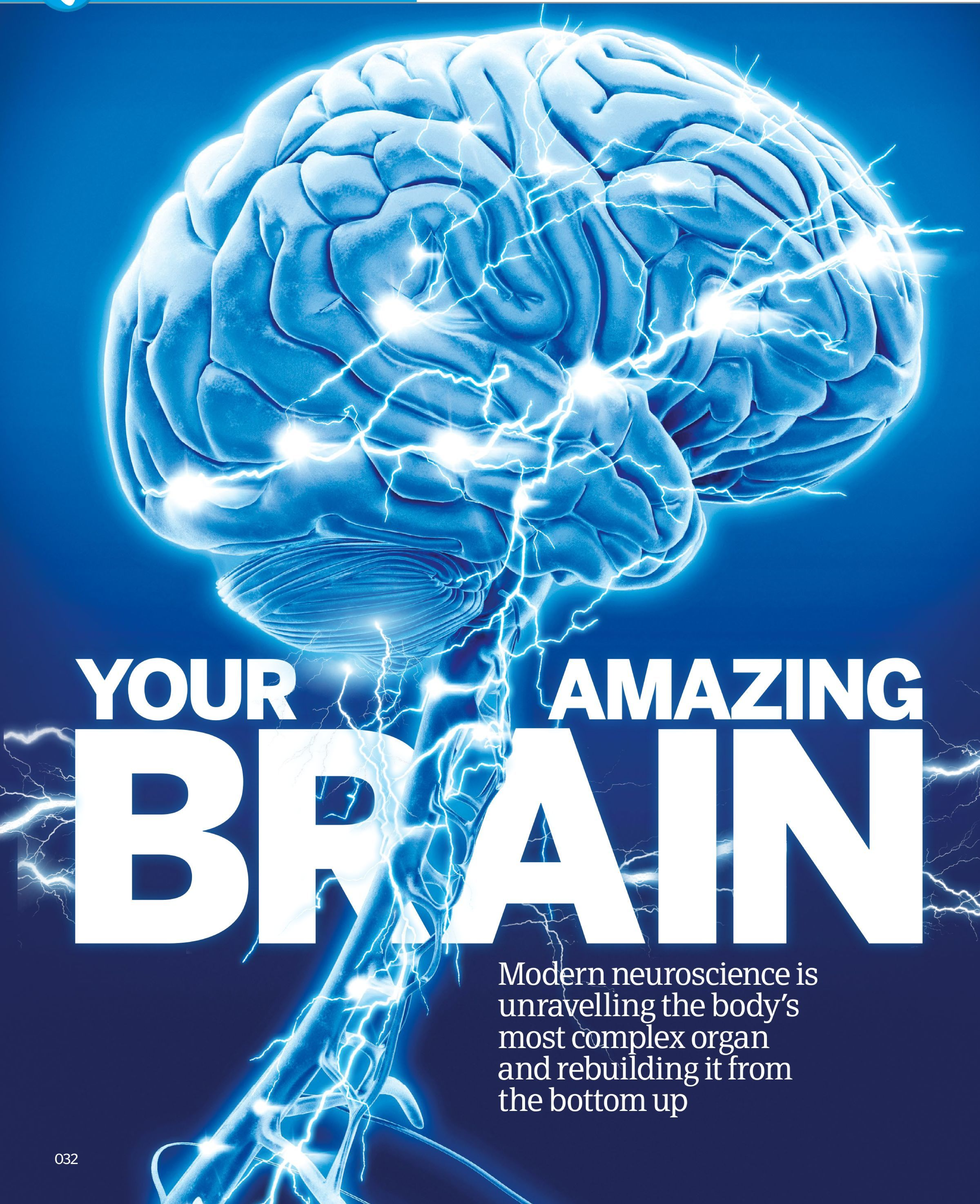
Birth
From the moment of birth, babies' brains start making millions of new connections every minute.

Sensory (yellow)
Babies have to make sense of the world around them. Connections involved in vision and hearing are the first to develop.

Language (blue)
It takes babies six months to develop the connections they need to start recognising words and trying to talk.

Higher cognitive function (red)
Complex thought processes like working memory, imagination and consciousness take years to develop.

© SPL; Getty; Thinkstock



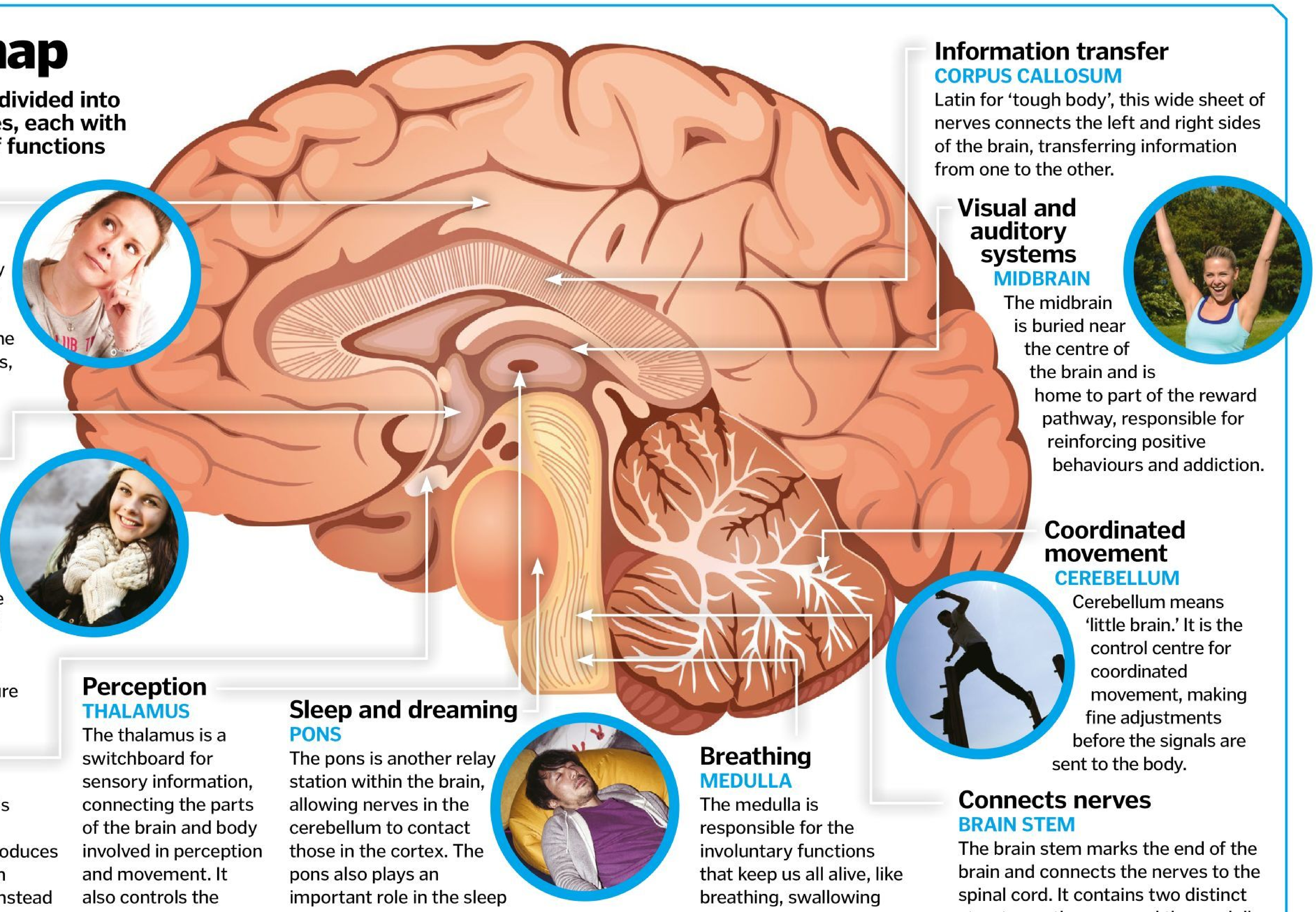
YOUR AMAZING BRAIN

Modern neuroscience is unravelling the body's most complex organ and rebuilding it from the bottom up

DID YOU KNOW? *When Albert Einstein died in 1955, pathologist Thomas Harvey stole his brain, cut it up and preserved it in jars*

Brain map

The brain can be divided into distinct structures, each with a specialist set of functions



Memory
CEREBRUM

The cerebral cortex makes up the majority of the human brain. It is divided into four lobes, which handle the most complex of tasks, including planning, memory and vision.

Temperature and hydration
HYPOTHALAMUS

The hypothalamus is responsible for maintaining equilibrium within the body. It monitors and adjusts a variety of vital parameters, like the body's temperature and hydration.

Hormones
PITUITARY GLAND

This pea-sized gland is connected to the hypothalamus and produces hormones, passing on chemical messages instead of electrical impulses.

Perception
THALAMUS

The thalamus is a switchboard for sensory information, connecting the parts of the brain and body involved in perception and movement. It also controls the sleep/wake cycle.

Sleep and dreaming
PONS

The pons is another relay station within the brain, allowing nerves in the cerebellum to contact those in the cortex. The pons also plays an important role in the sleep cycle and dreaming.

Breathing
MEDULLA

The medulla is responsible for the involuntary functions that keep us all alive, like breathing, swallowing and heartbeat.

Information transfer
CORPUS CALLOSUM

Latin for 'tough body', this wide sheet of nerves connects the left and right sides of the brain, transferring information from one to the other.

Visual and auditory systems
MIDBRAIN

The midbrain is buried near the centre of the brain and is home to part of the reward pathway, responsible for reinforcing positive behaviours and addiction.

Coordinated movement
CEREBELLUM

Cerebellum means 'little brain.' It is the control centre for coordinated movement, making fine adjustments before the signals are sent to the body.

Connects nerves
BRAIN STEM

The brain stem marks the end of the brain and connects the nerves to the spinal cord. It contains two distinct structures, the pons and the medulla.

The human brain is the most complicated structure in the known universe. It has taken hundreds of millions of years of evolution to construct, and over the last seven million years, it has tripled in size. It weighs little more than a bag of sugar, but packed inside it are 86 billion neurones, linked together by over 100 trillion connections in a network more powerful than even the most advanced supercomputers ever built.

By far the largest part of the human brain is the forebrain, and like the brains of other mammals, it is covered in a thick layer of neurones known as the cerebral cortex. But in humans, this layer has been massively expanded. The human cerebral cortex has 1,000 times as many neurones as the same structure in a mouse, and it has not yet stopped evolving.

The smallest processing units in the cortex are known as neocortical columns, where each contains thousands of different connections. Over the course of evolution, these neocortical columns have been duplicated over and over again, until space in the skull started to run out. The cortex developed deep ridges and folds to fit more and more processing power into the same tiny space, and if unfolded, would cover an area measuring two square metres (21.5 square feet).

The neurones that make up the brain crisscross over one another in a vast network and each individual cell makes up to 10,000 connections, building the most complex circuit in history.

In 2013, a team at the Centre for Regenerative Therapies in Dresden, Germany, examined the formation of neurone connections in cloned mice. They wanted to learn how much the structure of the brain is influenced by life experience. Because the mice were clones, each was genetically identical, meaning that any differences in their brains would be purely down to their environment.

The mice lived in large cages, with lots of toys and places to explore, and after just a few months, differences became apparent in their brains. The most excitable, outgoing, curious mice had many more new nerves and new connections than their lazier counterparts; their brains had adapted as they learnt.

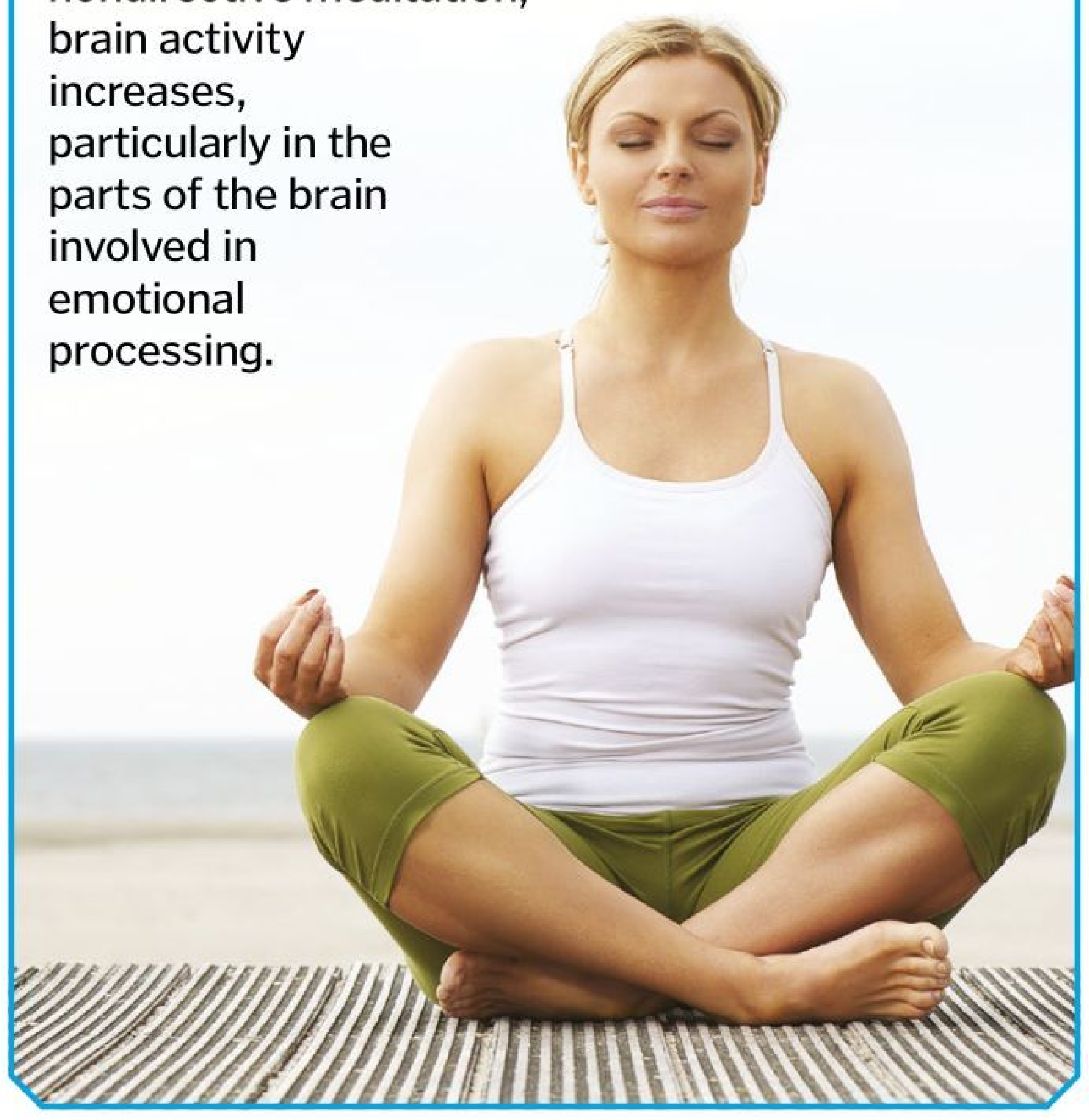
While the underlying fabric of the brain is the same, every neurone in every brain is different, and each makes its own unique path. Every brain is wired differently, and the unique set of connections is based on experiences.

Mapping the connections in the human brain is an enormous task and work is ongoing. The Human Connectome Project, launched in 2009,

Finding peace

Meditation has been practised for thousands of years as a means to relax, think, or to find enlightenment. In 2014, an international team of researchers, based in Norway and Australia, collaborated to understand why it is such a powerful tool.

There are two types of meditation; concentrative, where a person focuses on specific thoughts; and nondirective, where they let their mind wander. By studying fMRI scans of experienced meditation practitioners, the team discovered that when you let your mind wander in nondirective meditation, brain activity increases, particularly in the parts of the brain involved in emotional processing.



is designed to map the intricate connections between all of the neurones in the human brain, in an effort analogous to the Human Genome Project. Computers can be programmed to trace the paths of neurones through brain-scan images, but even the most advanced machines make mistakes, and everything has to be double-checked by a human.

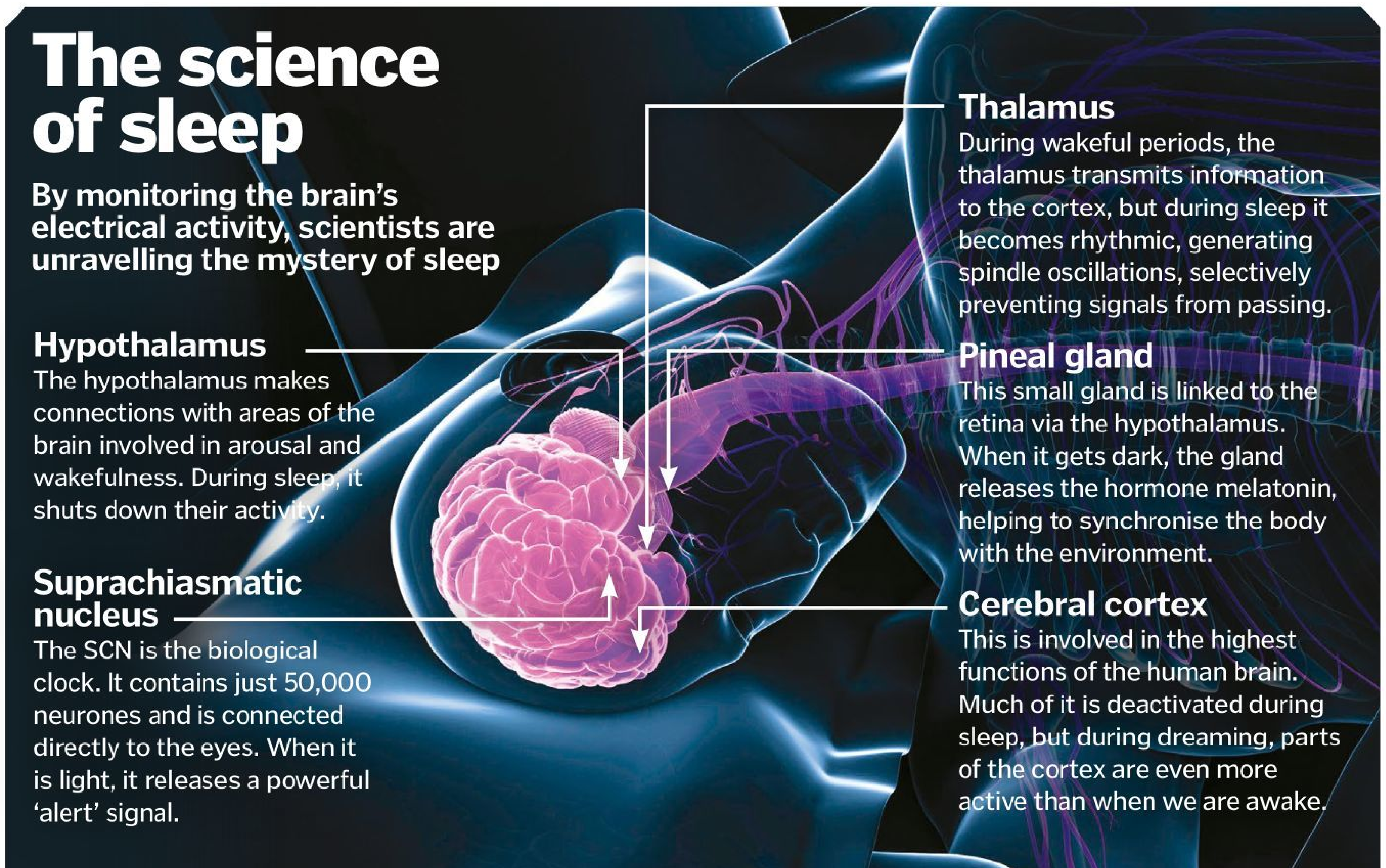
As an alternative, some research teams are trying a new approach, where instead of using computers to analyse the data they are using volunteers. In 2011, the online game *Foldit* made the headlines when players managed to solve a decade-old biological question. By tapping into the spatial skills of videogamers, researchers used volunteers to solve three-dimensional protein puzzles that a computer would struggle to complete. By simply playing the game, hundreds of people worked together to help solve the structure of a protein made by a simian retrovirus that causes AIDS-like symptoms in monkeys.

This approach is now being extended to the field of neuroscience and crowd-sourcing is being used to map the connections between neurones in the back of the eye. Tracking the intricate pathways of neurones in the brain is a difficult task for computers, but people are much better at spotting patterns.

EyeWire is a project designed to map the nerve connections in the human retina. Players are given a half-finished neurone and asked to work through slices of the brain, colouring in the connections. Each cube section is manually checked multiple times by different people, so if someone makes a mistake it is averaged out by the community. More experienced players oversee the work and can make changes if they feel they are needed. This approach speeds up the process by thousands of times.

The science of sleep

By monitoring the brain's electrical activity, scientists are unravelling the mystery of sleep



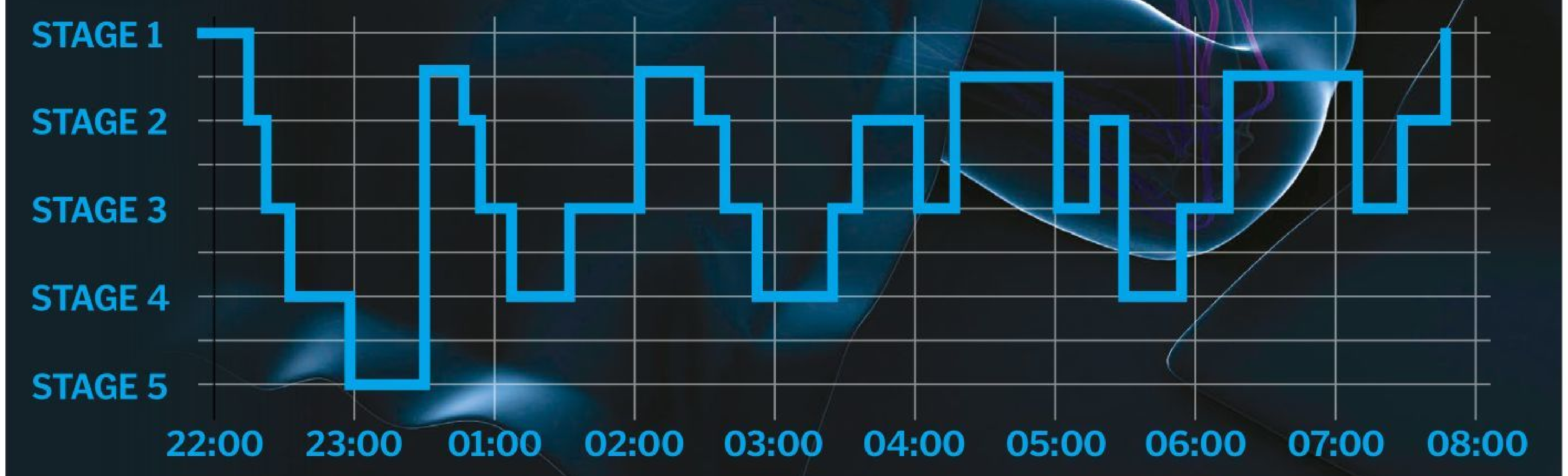
Hypothalamus
The hypothalamus makes connections with areas of the brain involved in arousal and wakefulness. During sleep, it shuts down their activity.

Suprachiasmatic nucleus
The SCN is the biological clock. It contains just 50,000 neurones and is connected directly to the eyes. When it is light, it releases a powerful 'alert' signal.

Thalamus
During wakeful periods, the thalamus transmits information to the cortex, but during sleep it becomes rhythmic, generating spindle oscillations, selectively preventing signals from passing.

Pineal gland
This small gland is linked to the retina via the hypothalamus. When it gets dark, the gland releases the hormone melatonin, helping to synchronise the body with the environment.

Cerebral cortex
This is involved in the highest functions of the human brain. Much of it is deactivated during sleep, but during dreaming, parts of the cortex are even more active than when we are awake.



Stage 1
The first stage of sleep is the transition period. It is very light and lasts just a few minutes. As the brain shuts down, there can be some twitching as the muscles relax.

Stage 2
As people enter the second stage of sleep, their breathing and heart rate slow down and their body temperature drops. Around half of sleep time is spent in stage-2 sleep.

Stage 3
The third stage of sleep is described as 'deep sleep' and is characterised by the presence of a slow delta-wave pattern, representing the underlying activity of the brain stem.

Stage 4
We spend about ten per cent of the night in this deep sleep stage. Breathing is rhythmic and there is little muscle movement. Blood pressure drops and growth and repair process can begin.

Stage 5
Up to about five times a night, we enter rapid eye movement (REM) sleep. The brain returns to normal levels, but we remain unconscious and have dreams of five to 30 minutes each.

The developing brain

Baby
In order to fit through the birth canal, human babies must be born well before their brains have finished developing, so their brains grow rapidly in their first years. Experiences prompt the development of new connections between nerves, and by the time a baby is two years old, it has 1.5 times as many synapses as an adult.

Infant
Support cells, known as glia, provide protection, insulation and nutrition for the brain's nerve cells. Throughout childhood, they continue to migrate and grow. During the first two to three years of a child's life, the insulating white matter of the still-developing brain begins to form.

Child
By the age of ten or 11, the rapid development of new connections in the brain has ended and a period of trimming and pruning begins. Instead of creating extra pathways, the brain focuses in on the most important, strengthening and insulating those that are used more often and losing ones that are no longer valuable.

DID YOU KNOW? *You sleep for around a third of your life and have around five dreams every night*

Making memories

The human brain has an amazing capacity for retaining information

SENSORY MEMORY

The body is constantly bombarded by sensory signals and most incoming sensory information is retained for less than a second before it is forgotten.

TRANSFER

The hippocampus integrates incoming sensory information, collecting it together as a single experience. It works together with the cortex to prioritise which information to store and which to forget.

SHORT-TERM MEMORY

Without concentrating too hard, short-term memory can hold around seven items for 20 to 30 seconds. Collecting information into discrete chunks, like splitting a phone number up into sections, can help the brain retain more.

ACOUSTIC ENCODING

Short-term memory tends to be based on sound, also known as echoic memory. When trying to remember a phone number, it often helps to rehearse it vocally in your head.

LONG-TERM MEMORY

The hippocampus is essential for the transfer of memories from short to long-term storage. Some of this memory consolidation happens in dreaming as the brain rehearses the day's activities.

SEMANTIC ENCODING

Instead of being linked to an audio memory, long-term memories tend to be stored more abstractly, by concept. Other memories are stored as sensory echoes, allowing entire experiences to be remembered and reconstructed.

CONSOLIDATION

Once the trace of a memory is formed, the pathway can be consolidated with use. The more often a synapse is used, the stronger it becomes.

NEURONE CHANGES

If a synapse is used repeatedly, it becomes increasingly sensitive to stimulation, producing more receptors and strengthening the connection.

RECALL

Human memory is associative; it works by linking pieces of information together. Memories are not stored as individual entities, but reconstructed using several different parts of the brain.

IMPLICIT MEMORY

These types of memories do not require conscious recall and are often based on motor skills. By repeating tasks, like riding a bike or playing the piano, pathways become automatic.

EXPLICIT MEMORY

Explicit memories are accessed consciously. They can be stored as episodes, linked to a specific event or place, or stored by category as more abstract knowledge.

Photoshop creative
All About Space

RECOGNITION

The brain is very good at making associations, and incoming information is compared to stored data, allowing us to quickly recall things we already know or have experienced before.

ASSOCIATION

Memories are rarely stored in isolation and one pathway is linked to others. Recognition and recall can both trigger other related memories.

Teenager
Trimming and adjusting the brain starts at the back and works forward, continuing into the teenage years. The prefrontal cortex, involved in planning, judgement and emotional control, is the last to be finished. Research also suggests that adolescents' body clocks are wired differently, so they naturally go to bed and wake up later.

Adult
Most growth and remodelling is complete by our early-20s, but new connections continue to form in the adult brain, albeit at a much slower rate than in children. Staying active and providing the brain with engagement and stimulation strengthens existing connections, and new pathways continue to form as we learn.

Old age
Damage to the brain cannot easily be repaired, so as it ages, signs of wear start to appear. Connections are lost as nerve cells wither, or as debris builds up between synapses, and gradually mental function can decline, leading to age-related illnesses like Alzheimer's disease and Parkinson's.

Although projects like EyeWire provide a detailed and biologically accurate picture of what is going on inside the human brain, rebuilding the entire structure using this method will still take decades. The alternative is to simulate the brain, taking what we already know and using it as a scaffold to build the parts we have yet to study. By going back and testing the model brain against the real data, scientists can check that their simulation is working as it should.

Japan's K Computer is one of the fastest and most powerful in the world, and in 2014, 83,000 of its processors were combined in order to simulate one per cent of one second of human brain activity. This was a huge achievement, but it took the machine 40 minutes and barely represented a fraction of the power of the human brain.

The problem is that most modern computers are built on architecture completely different to the human brain. The brain is made up of processing cores, capable of specialising to perform highly specific tasks. They are less precise, but have much more flexibility, and most importantly, the capacity to learn. Memories are not stored in one particular place, and are instead distributed across the network. In contrast, modern computers use programs in order to decide what to do, and they store elements in a hierarchical memory.

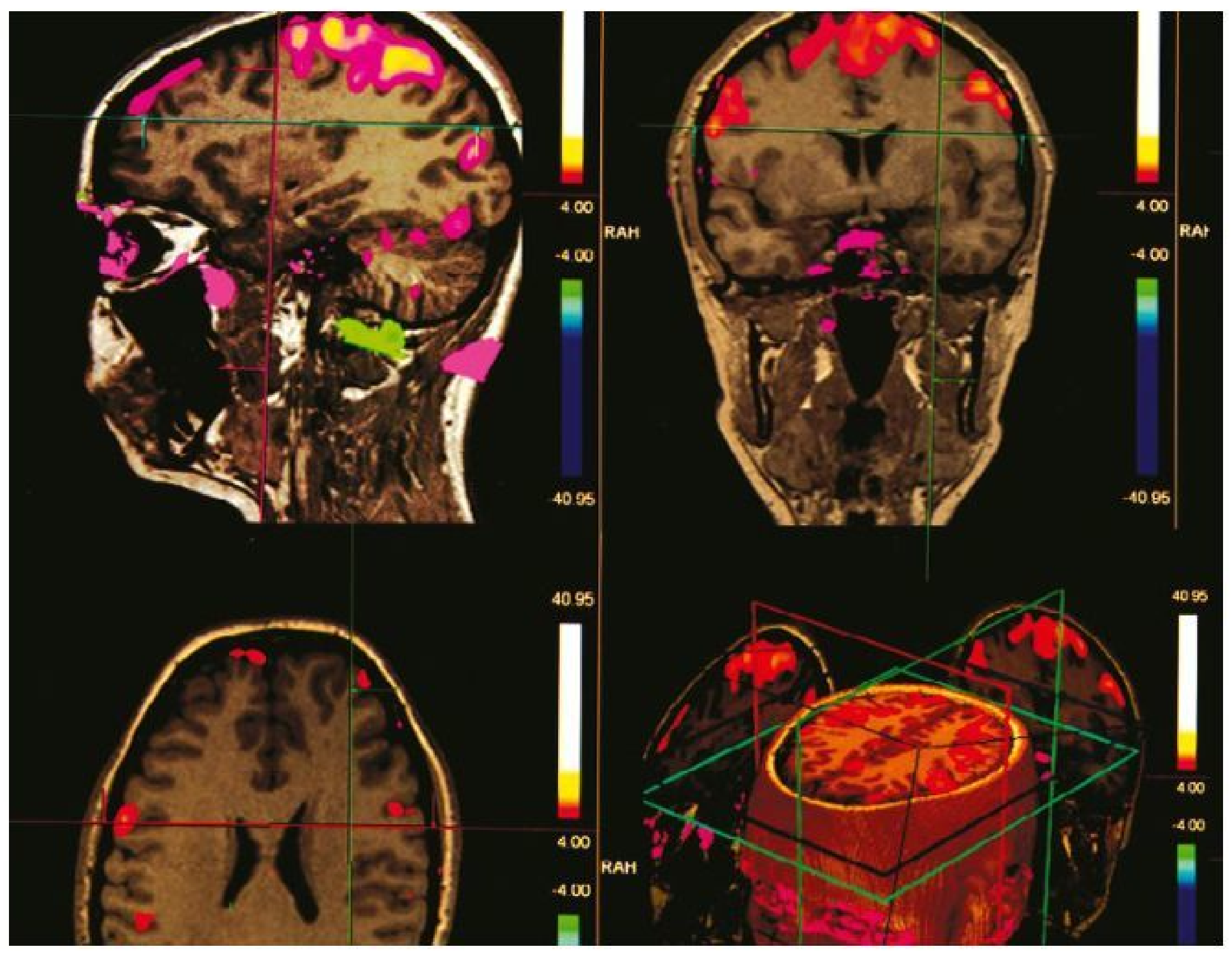
In 2013, the European Commission funded the Human Brain Project with a grant of €1 billion (£800 million/$1.3 billion) in order to accomplish just that. This ambitious, ten-year endeavour aims to develop cutting-edge computational tools to assist in the understanding of brain function, bringing together the fragments from different disciplines and providing an unprecedented map of human brain activity. The Human Brain Project hopes to use this information to build a supercomputer capable of simulating the network that makes up the human brain. They estimate that it would take one laptop to

Imaging the brain

Take a look at the most common techniques used to study the living brain

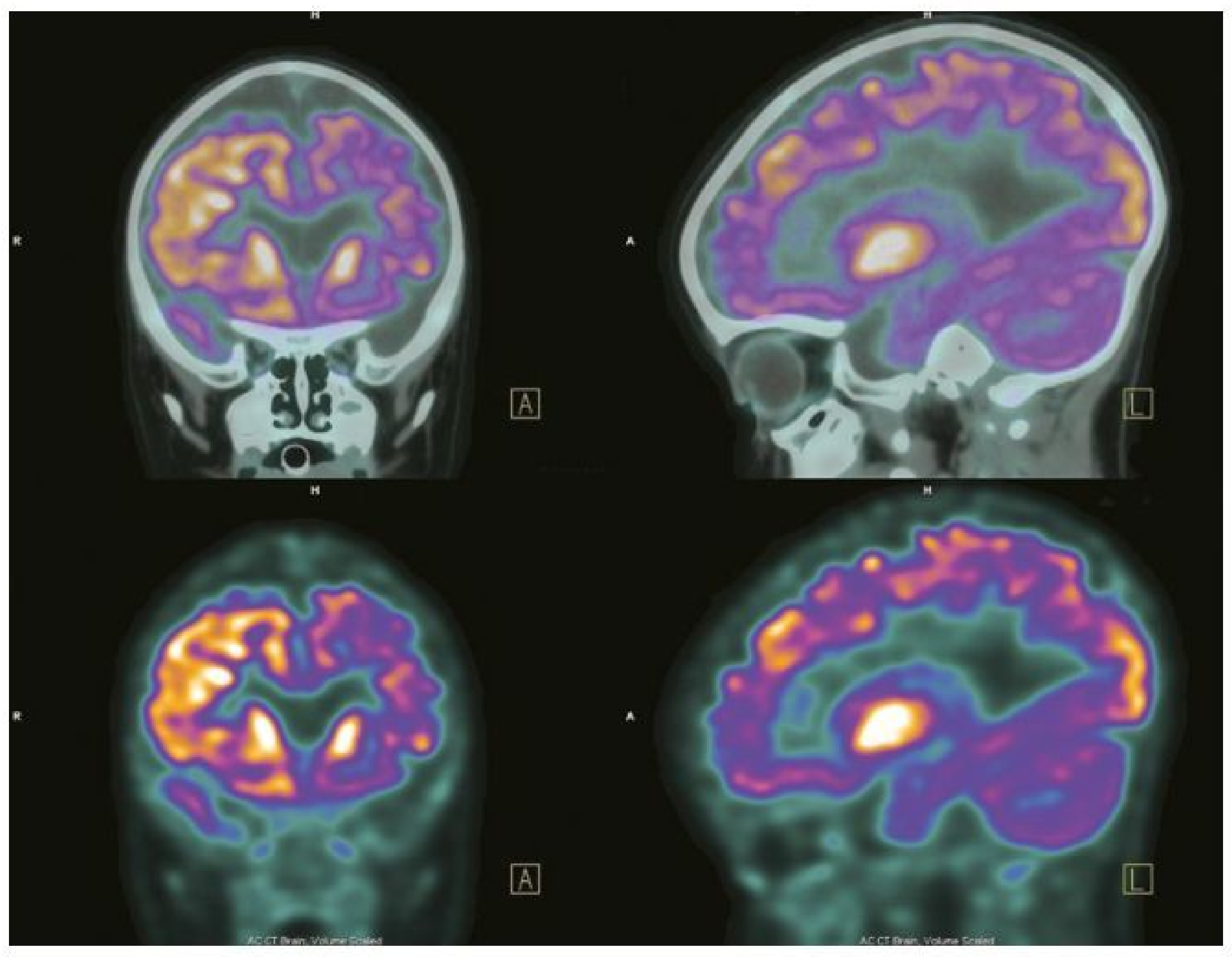
CT

Computed tomography (CT) scans use X-rays to build a three-dimensional image of the brain. The radiation travels at different speeds through different tissues, allowing a density map to be produced. It provides purely structural information and is useful for identifying tumours.



fMRI

Functional Magnetic Resonance Imaging detects the amount of oxygen present in the blood, allowing brain activity to be mapped. When regions of the brain become more active, their demand for blood rises and they light up on the image. It captures a picture of the activity of the entire brain every two seconds.

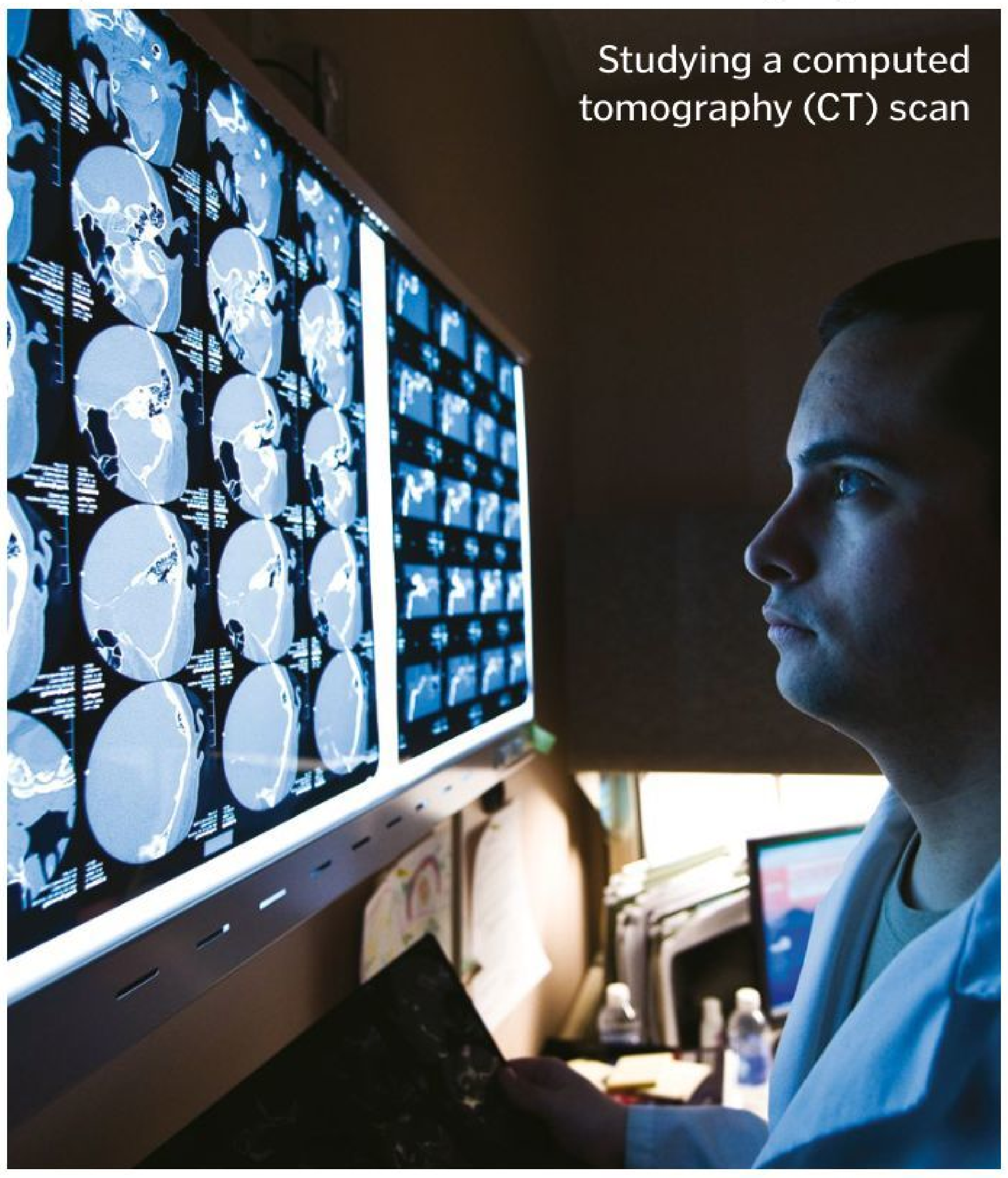


PET

Positron Emission Tomography uses safe radioactive isotopes to measure brain activity. By labelling oxygen or sugar with radioactive tags, blood flow in the brain can be monitored. The tags emit low-energy radiation and as blood is diverted to active regions of the brain, the emissions pinpoint the locations.

EEG

Electroencephalograms take advantage of the electrical signals produced by nerves to produce a map of brain function. Electrodes placed on the scalp are able to detect the patterns of nerve activity beneath the surface. This technique is particularly useful for sleep studies.



Studying a computed tomography (CT) scan

DID YOU KNOW? *A human brain weighs around four times as much as a chimpanzee's brain*

Brain damage

Different injuries affect the brain in different ways

SEVERE

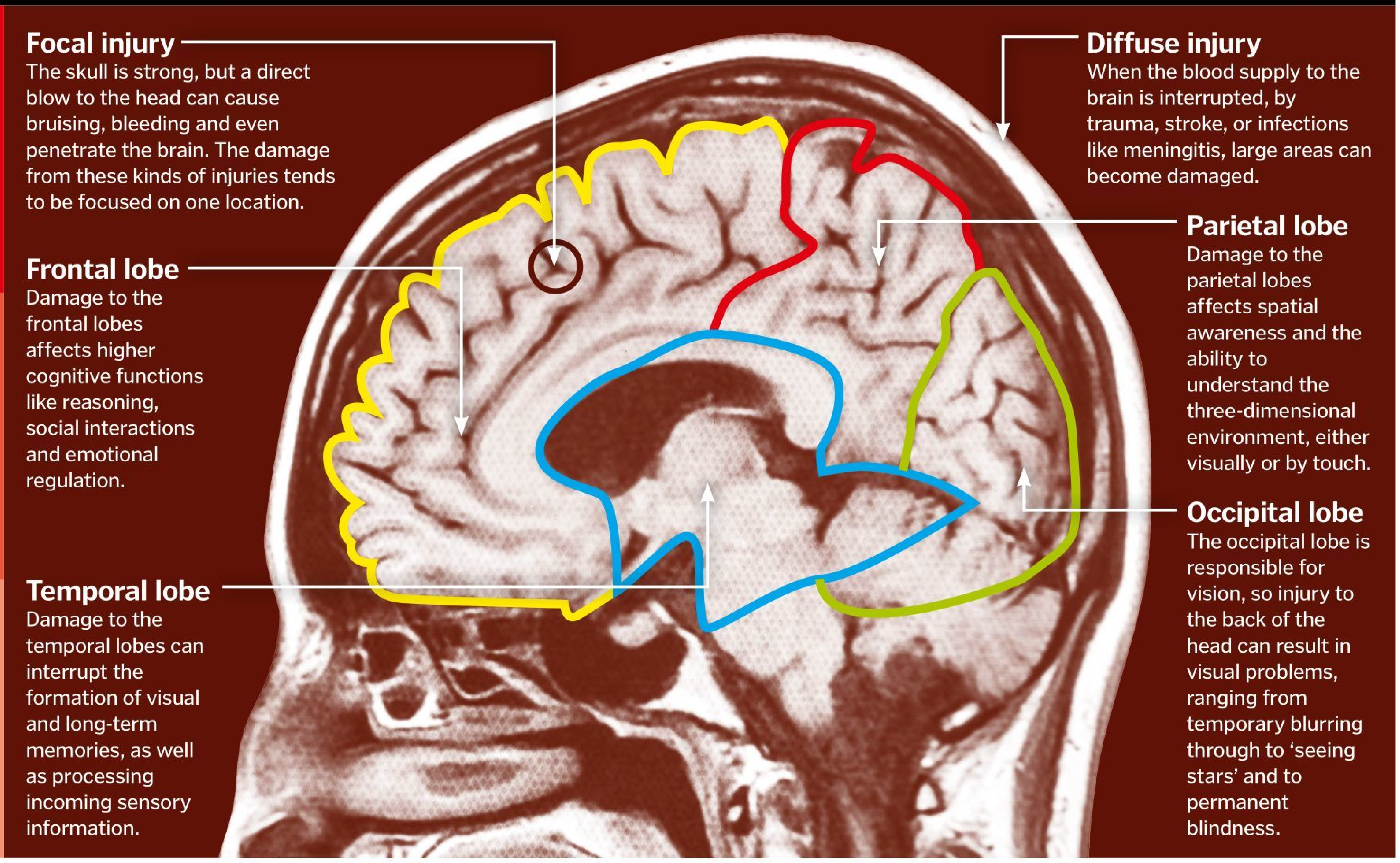
If the injury is severe, the patient is no longer able to respond to sensory stimulation. Their eyes remain closed and there is no response at all to verbal cues.

MODERATE

When brain injury is more severe, verbal communication starts to break down and patients no longer respond normally to pain.

MILD

With mild brain injury, patients may be confused, but they remain aware, conscious and conversational.



Focal injury
The skull is strong, but a direct blow to the head can cause bruising, bleeding and even penetrate the brain. The damage from these kinds of injuries tends to be focused on one location.

Frontal lobe
Damage to the frontal lobes affects higher cognitive functions like reasoning, social interactions and emotional regulation.

Temporal lobe
Damage to the temporal lobes can interrupt the formation of visual and long-term memories, as well as processing incoming sensory information.

Diffuse injury
When the blood supply to the brain is interrupted, by trauma, stroke, or infections like meningitis, large areas can become damaged.

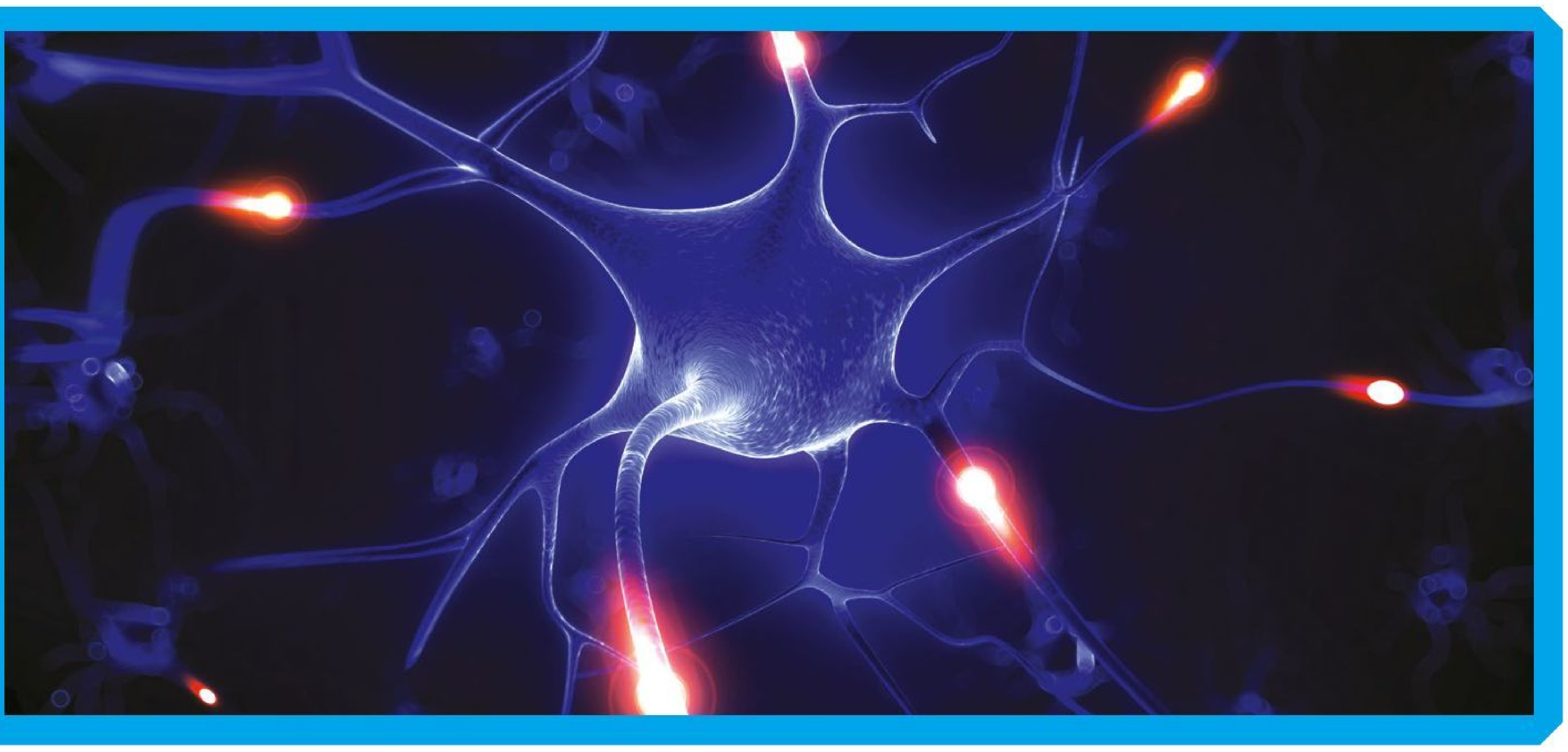
Parietal lobe
Damage to the parietal lobes affects spatial awareness and the ability to understand the three-dimensional environment, either visually or by touch.

Occipital lobe
The occipital lobe is responsible for vision, so injury to the back of the head can result in visual problems, ranging from temporary blurring through to 'seeing stars' and to permanent blindness.

Can the brain heal?

The human brain has limited capacity for repair, so once a region is injured, it cannot be replaced. The damaged cells are removed and support cells known as astrocytes divide to form a wall around the gap to seal off the area. The space then becomes filled with fluid. However, all is not lost.

The human brain is a remarkable organ and although it cannot repair itself as such, it is able to adapt. Nerves are not fixed in their function, or their connections, so if a part of the brain is injured, new connections can be made to bypass the damage. The amount of function that can be regained depends on the location and severity of the injury and can be greatly aided by rehabilitation, encouraging the formation of new pathways in the brain.



simulate the activity of one neurone and are working closely with IBM to develop powerful neuromorphic supercomputers.

Neuromorphic chips are computer chips modelled on the architecture of the human brain. IBM released a chip modelled on the human brain in 2014. Known as the SyNAPSE chip, it has one million 'neurones' connected by 256 million 'synapses.' They are arranged into 4,096 'synaptic cores', which function in parallel with one another, just like the processing cores in the brain. Just like the brain, they operate on demand and can compensate if one core happens to fail.

By feeding these computers with inputs that mimic biological signals, scientists can then examine the electrical activity and can see where information is being processed and stored. The project is a collaboration between over 100 institutions in 24 countries.

New technology is the key to modelling a structure as complex as the human brain, and other international efforts are also in place to provide new technology. In 2013, US President Barack Obama announced the Brain Research through Advancing Innovative Neurotechnologies (BRAIN) initiative. The NIH (National Institutes of Health) allocated £24 million ($40 million) in 2014 to develop new technologies to find the best way to understand the brain. In order to break the brain down and rebuild it accurately, the project combined silicon-based techniques and advancements in stem-cell biology, brain imaging and medical drug development.

The practical applications of this future technology are incredible, but we are already able to interface with the brain in more ways than ever before. Light-sensitive retinal implants can restore sight to the blind by sending electrical signals to the optic nerve, while auditory brainstem implants communicate sound signals directly to the brain in patients who are profoundly deaf.

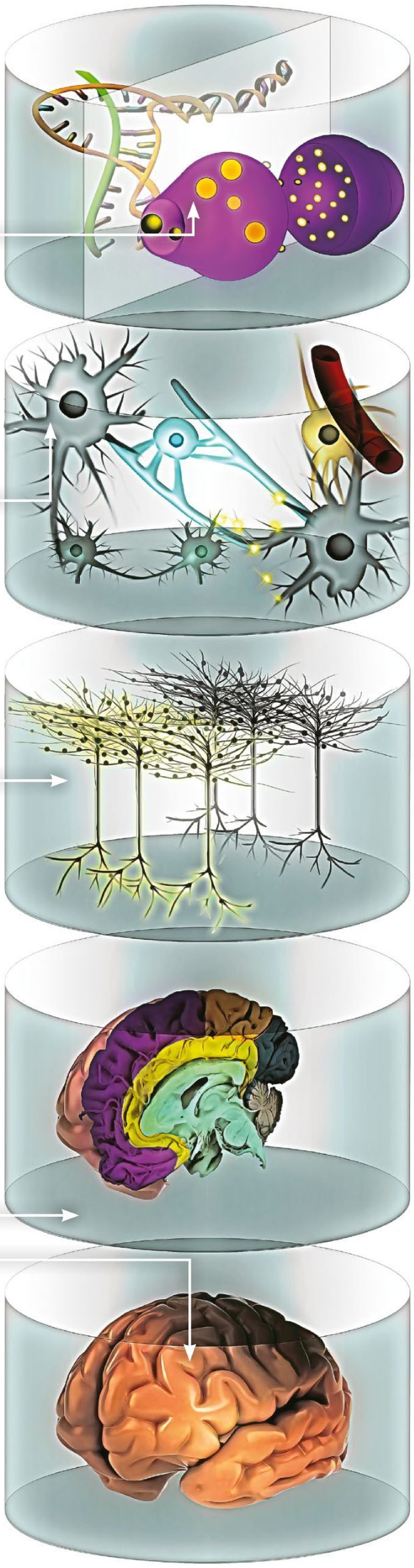
However, one of the most incredible technological developments of all is the BrainGate system, first revealed in 2006. The technology

Cutting-edge neuroscience

The human brain is one of the most complex structures in the known universe and understanding how it works is an enormous scientific undertaking. Modern neuroscience brings together experts from a huge array of fields and by using a combination of the most advanced technologies, medical techniques, biological research and computational modelling, scientists are finally beginning to untangle the many profound mysteries of the human brain.

Building a brain

Large-scale projects aim to simulate the human brain at every level



DNA and neurotransmitters

At the molecular level, scientists are able to manipulate the 3D structures of proteins using computer programmes, and to model the effects that changes might have. Such techniques are hugely useful in drug design.

Nerves and support cells

In order to gain a proper understanding of how the brain functions, many scientists advocate a bottom-up approach. By creating digital neurones based on the underlying rules and principles of biology, it is hoped that the complex network of the brain can be simulated.

Neural pathways

Some projects aim to map all of the connections in the human brain, generating a 3D representation of the intricate wiring. Others aim to simulate the process, allowing the computer to make its own connections based on biological rules.

Lobes and structures

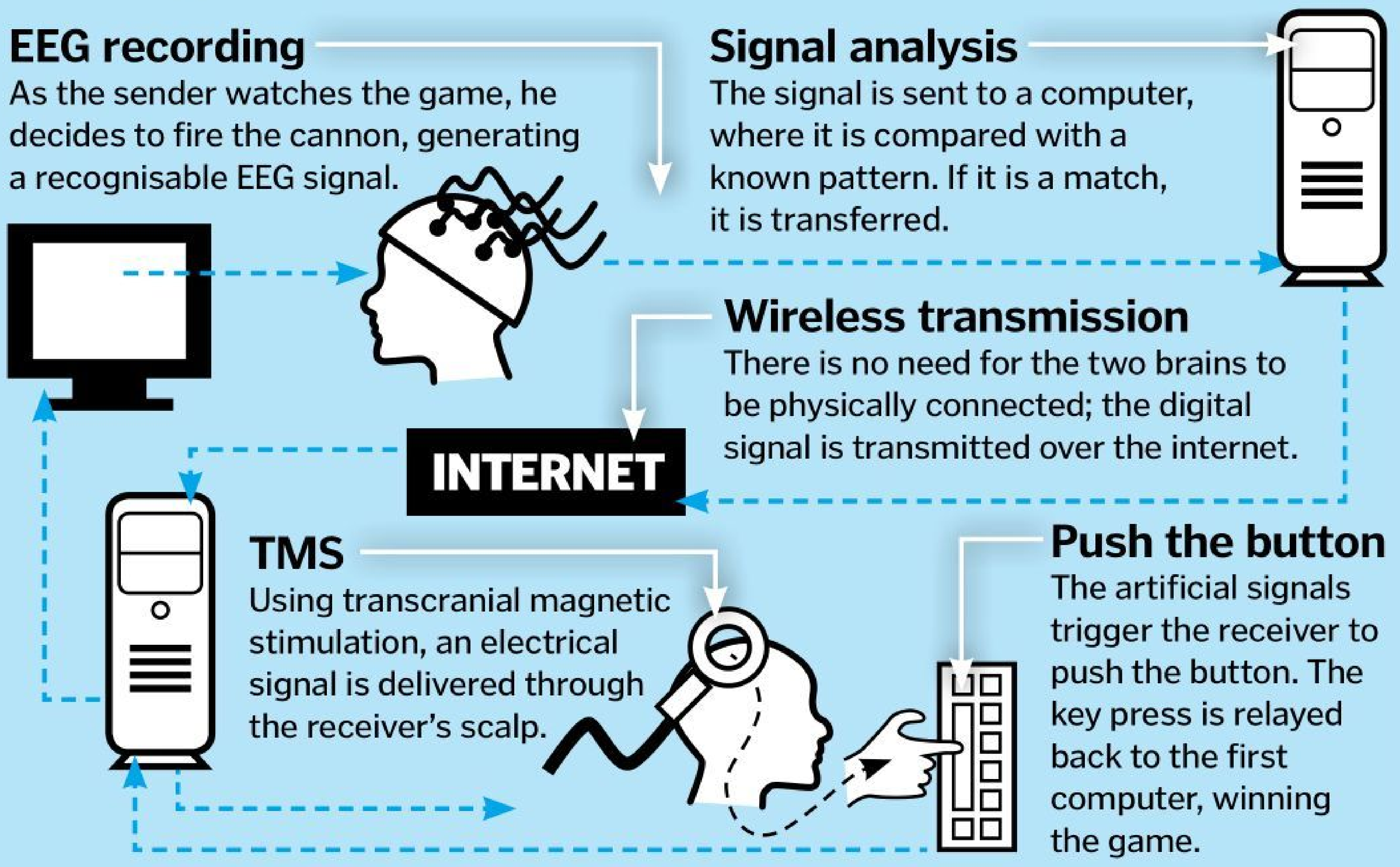
Simulations will allow information about different structures in the brain to be integrated, enabling scientists to more closely examine the interactions between different areas, or even to remove one region and study it in isolation.

Whole brain

In 2013, the K Computer in Japan carried out one second of simulated human brain activity. With 705,024 processor cores, it took the machine 40 minutes to simulate a network just one per cent of the size of the human brain. Advanced processors due in the next ten years or so will increase this capability significantly.

How mind control works

Simple equipment and complex computer programming allow our thoughts to be transmitted over the internet



EEG recording
As the sender watches the game, he decides to fire the cannon, generating a recognisable EEG signal.

Signal analysis
The signal is sent to a computer, where it is compared with a known pattern. If it is a match, it is transferred.

Wireless transmission
There is no need for the two brains to be physically connected; the digital signal is transmitted over the internet.

TMS
Using transcranial magnetic stimulation, an electrical signal is delivered through the receiver's scalp.

Push the button
The artificial signals trigger the receiver to push the button. The key press is relayed back to the first computer, winning the game.

Mind control

In a groundbreaking experiment in 2013, researchers at the University of Washington successfully linked two human brains together and proved their principle with a video game.

The city is under attack by pirates, where player one, the sender, must intercept their rockets. They can see the screen and are armed with a cannon, but they do not have a keyboard and cannot press 'fire'. Player two, the receiver, is sitting in another room; he cannot see the game, but he does have a keyboard. Player one thinks about firing the cannon, and fractions of a second later, player two pushes the button, saving the city and winning the game.

Player one was wired up to an electroencephalogram (EEG) and his brain activity was being monitored. When he was thinking about pressing the button, there was a characteristic signal in the 'mu band' of the EEG, triggering the program to send a wireless signal to player two.

Player two was wearing a specially designed coil on his scalp that generated a magnetic field, positioned over the part of the brain that controls contraction in the right hand. The signal from player one was converted into magnetic stimulation, which in turn triggered electrical activity in the brain, causing player two to involuntarily fire the cannon.

DID YOU KNOW? *Your brain produces enough electricity to power a light bulb and consumes 20% of the oxygen you take in*

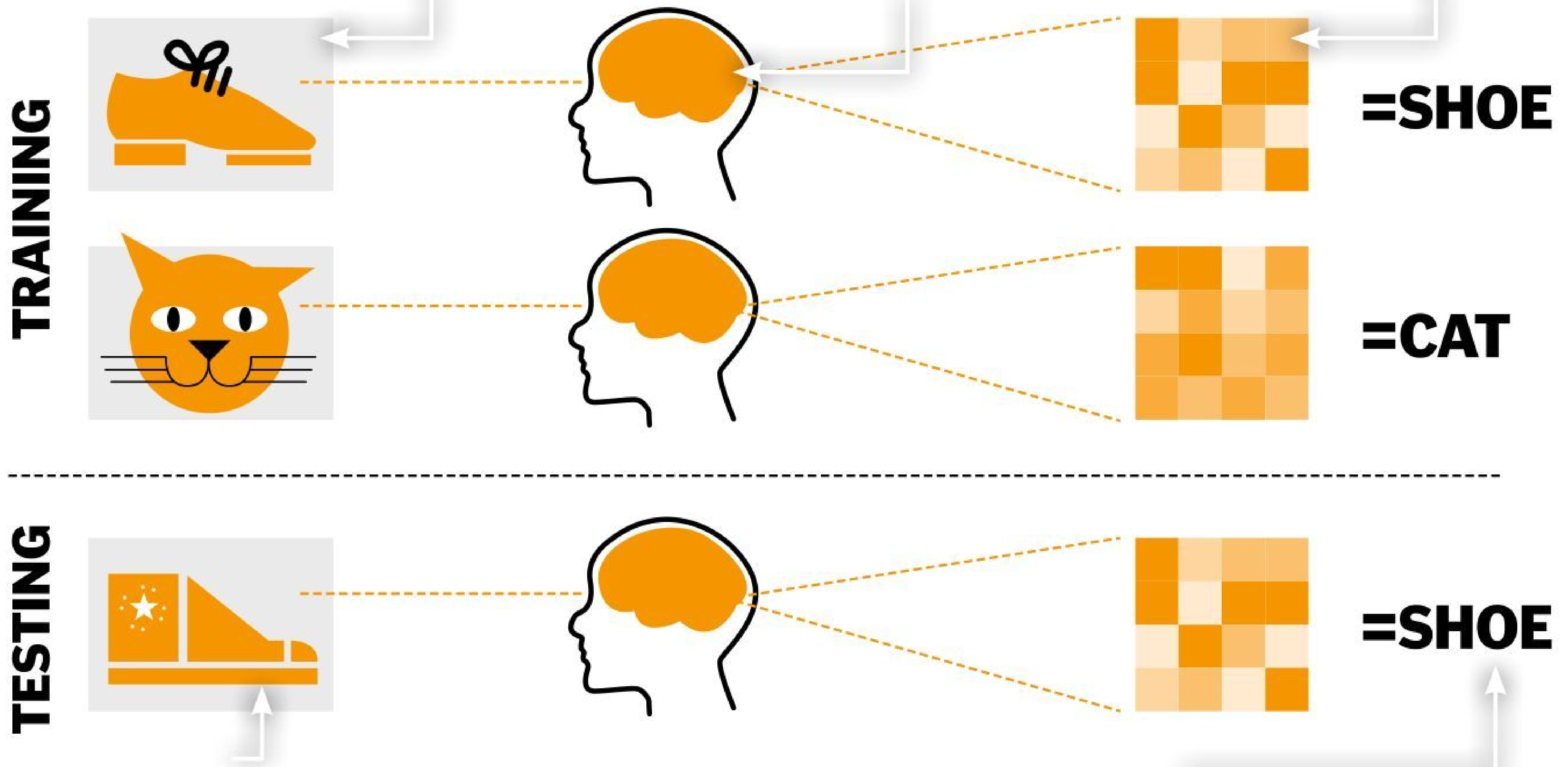
Decoding the brain

Computer programs can learn to decode brain-scan data and essentially read our thoughts

Training images
The program is trained using a series of images, alongside their corresponding fMRI patterns.

fMRI scan
Functional magnetic resonance imaging is used to identify the parts of the brain activated by different visual stimulation.

Voxel pattern
The fMRI data is stored as voxel patterns, three-dimensional grids of information.



Test image
When the subject is shown a new image, the program searches through its training database to find the nearest match.

Identification
If the program cannot find an exact match, it will use its training data to find a best estimate.

A machine that can read your mind

Have you ever wished someone else could see what you can see? In 2011, a team at the University of California, Berkley, developed a program that could tell what film you were watching just by reading your brain activity. The program could even read the images you were watching and display them on screen.

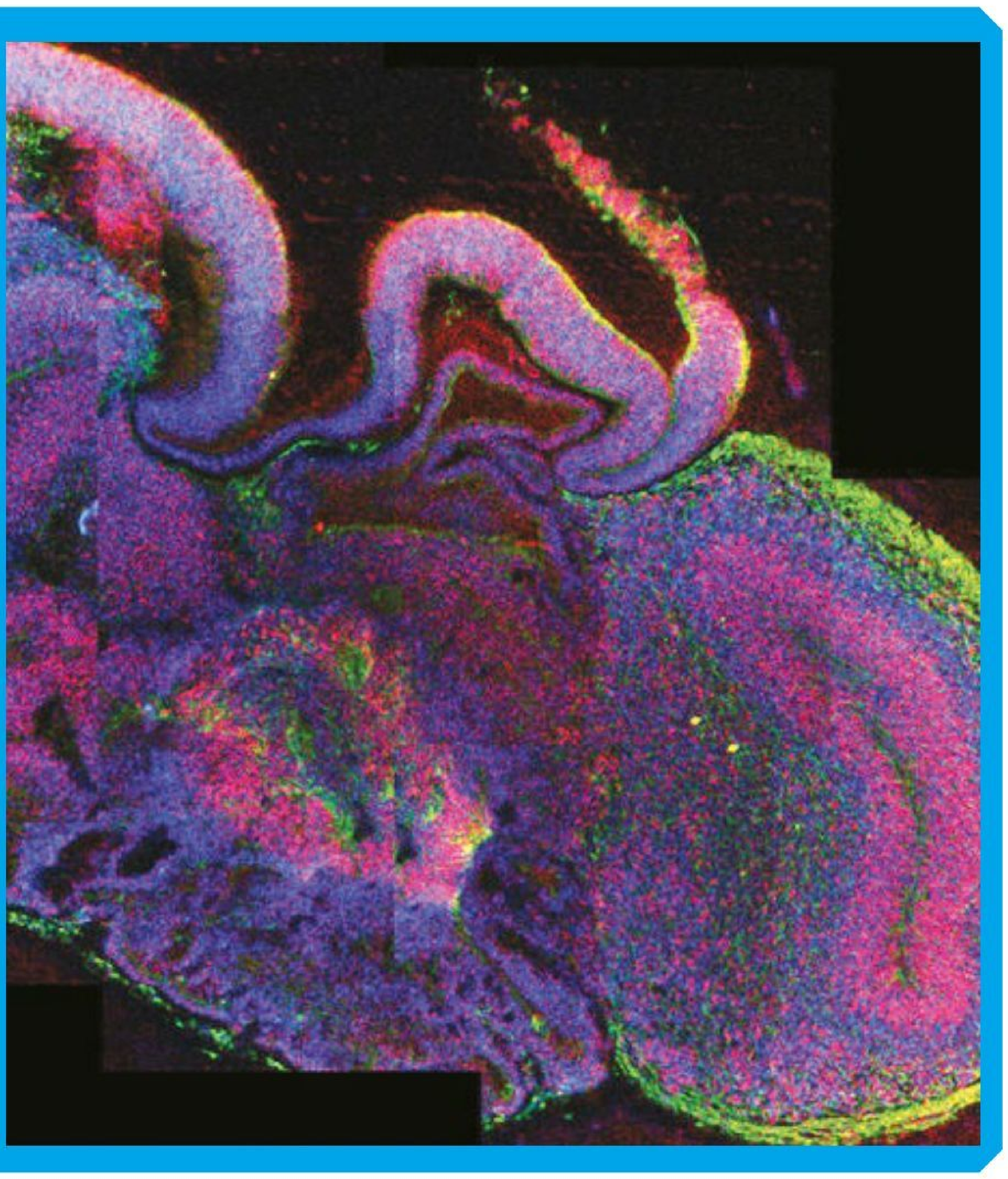
Volunteers were shown hours of video clips and for each one, their brain activity was mapped using functional magnetic resonance imaging (fMRI). The program was then trained to associate patterns of brain activity with their corresponding images.

Using this data set as a reference, the program was then shown new fMRI data recorded as people as they watched unknown clips. The program was able to compare the new data against its training data and guess what the test subject was watching by compiling and averaging the closest matches in to moving collages. The resulting images were eerily close to the originals.

Growing a brain

In 2013, scientists at the Austrian Academy of Sciences achieved something incredible; they grew part of a human brain in a Petri dish. Using a combination of embryonic stem cells and stem cells taken from adult skin, the team recreated the neuroectoderm; the embryonic structure that goes on to form the brain and the spinal cord.

The cells were put in three-dimensional scaffolds to give them something to grow around, and then given nutrients and oxygen and allowed to develop. Amazingly, the structures organised themselves into something resembling the brain of a nine-week old foetus. Some contained the pigmented cells of a retina, others developed a cortex and some even had a hippocampus. These mini-brains are about the size of a pea, and incapable of conscious thought, but could provide a valuable tool for researchers.



Get involved with EyeWire

Citizen scientists are needed to help untangle the neurones of the human retina

Developed by the Seung Lab at MIT, this browser-based game, known as EyeWire, is a project designed to map the neurones of the retina. Anyone can play; all you need is a computer and an internet connection.

EyeWire is a 3D puzzle game based inside a cube. The cube is divided into slices and hidden within them is the path of a neurone. All you have to do is scroll through and connect the slices together, tracing the path of the nerve cell through the cube.

As you work, a 3D model of your progress appears to the side of the screen and you can earn points based on how closely your model matches the models made by other players. You can earn points, level up and even participate in weekly competitions.

Every time you play, you are mapping actual neurones from the human retina, making a real contribution to scientific research.

To experience EyeWire yourself and to be a part of the research, simply click on the following URL: **https://eyewire.org/explore**

uses a sensor implanted on the motor cortex of the brain to pick up electrical signals generated when the patient thinks about moving. These signals are then decoded by a computer program and sent to a prosthetic limb. By carefully training the program to recognise specific signals, patients are able to move their bionic hands using just the power of their brains.

Taking electrical brain interfaces one step further, at the University of California, San Diego, researchers are using electricity to selectively erase memories. They have shown that by using particular frequencies of electrical pulses they can produce changes in the nerve cells in the brains of rats, making them forget traumatising experiences in their past.

As we continue to learn more about the connections in the brain, the possibilities for interacting with it will only continue to increase. The field of neuroscience is advancing faster than ever before, and huge international collaborations, like the Human Brain Project and the BRAIN initiative, are bringing mountains of research data together, creating resources that will revolutionise the field of neuroscience.

The puzzle of the human brain has been vexing scientists, doctors, and philosophers for thousands of years and understanding how it works is perhaps the most challenging problem in the history of science. However, with a combination of powerful new technology and international collaboration, the complexity of this mass of neurones is starting to unravel. Very soon, we might even be able to rebuild a functioning digital brain from the bottom up.

© Thinkstock; Dreamstime; Science Photo Library; Madeline A. Lancaster; University of Washington

YOUR SKELETON

This incredible living framework provides more than just structural support

The 206 bones of the adult human skeleton make up a strong, flexible framework that protects our vital organs and allows our bodies to move, as well as being a mineral store and stem-cell reserve.

Bone is a composite material, constructed from three basic ingredients: collagen strands, a sugary protein glue and inorganic calcium salts. The collagen fibres are arranged in alternating layers, crossing over one another, providing a flexible scaffold, and calcium salts are glued in between for strength and rigidity.

The outside of each bone is composed of plates, or hollow tubes, of dense cortical bone, supported on the inside by a honeycomb network of spongy trabecular bone. This network is slightly flexible and helps to distribute the load, curving the tensile and compressive forces across the ends of the bone, while providing maximum strength.

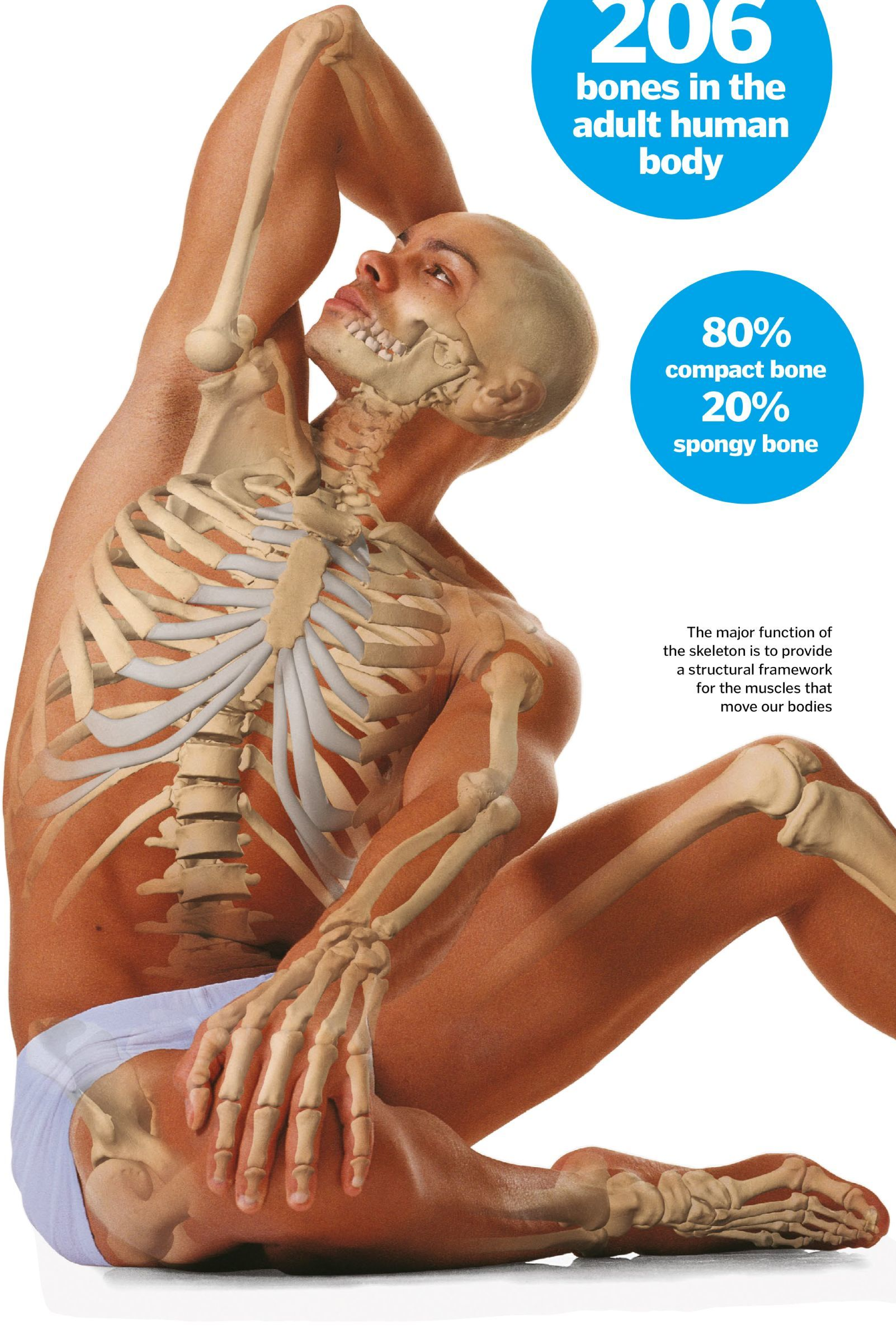
Spongy bone is also home to the bone marrow, which houses stem cells capable of producing most of the cells of the blood and immune system. They are constantly active, and millions upon millions of new red and white blood cells are produced every minute.

Embedded within the bone matrix are cells known as osteocytes. They do not move, but are capable of detecting stresses inside the bone itself, and can trigger the formation of new bone in a process known as remodelling. The old bone is broken down by large cells known as osteoclasts, and new collagen and minerals are deposited by smaller osteoblasts.

Together, the two cell types are able to release and store calcium and phosphorous in the skeleton for use elsewhere in the body. They are under the influence of hormones released by glands in the brain, and when levels of minerals run low in the body, the signals encourage the osteoclasts to begin wearing away at the surface of the bone, releasing minerals into the bloodstream. When mineral levels are high, osteoblasts lay down new bone, replenishing the store.

206
bones in the adult human body

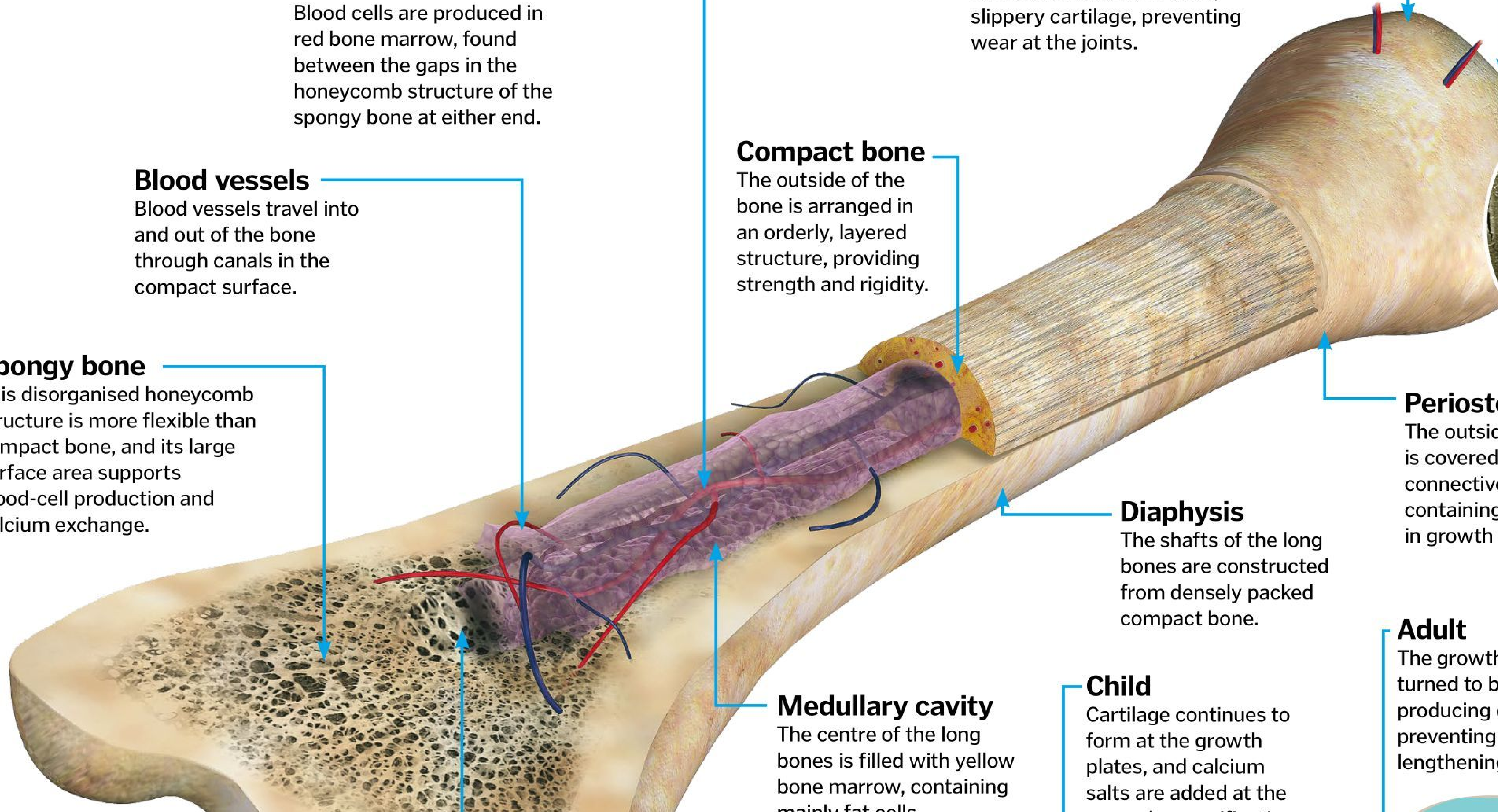
80%
compact bone
20%
spongy bone



The major function of the skeleton is to provide a structural framework for the muscles that move our bodies

Bone structure

The long bones are formed into tubes, closed at both ends and capped with cartilage



Red bone marrow
Blood cells are produced in red bone marrow, found between the gaps in the honeycomb structure of the spongy bone at either end.

Blood vessels
Blood vessels travel into and out of the bone through canals in the compact surface.

Spongy bone
This disorganised honeycomb structure is more flexible than compact bone, and its large surface area supports blood-cell production and calcium exchange.

Endosteum
The inner surface of the bone is lined by a single layer of cells.

Compact bone
The outside of the bone is arranged in an orderly, layered structure, providing strength and rigidity.

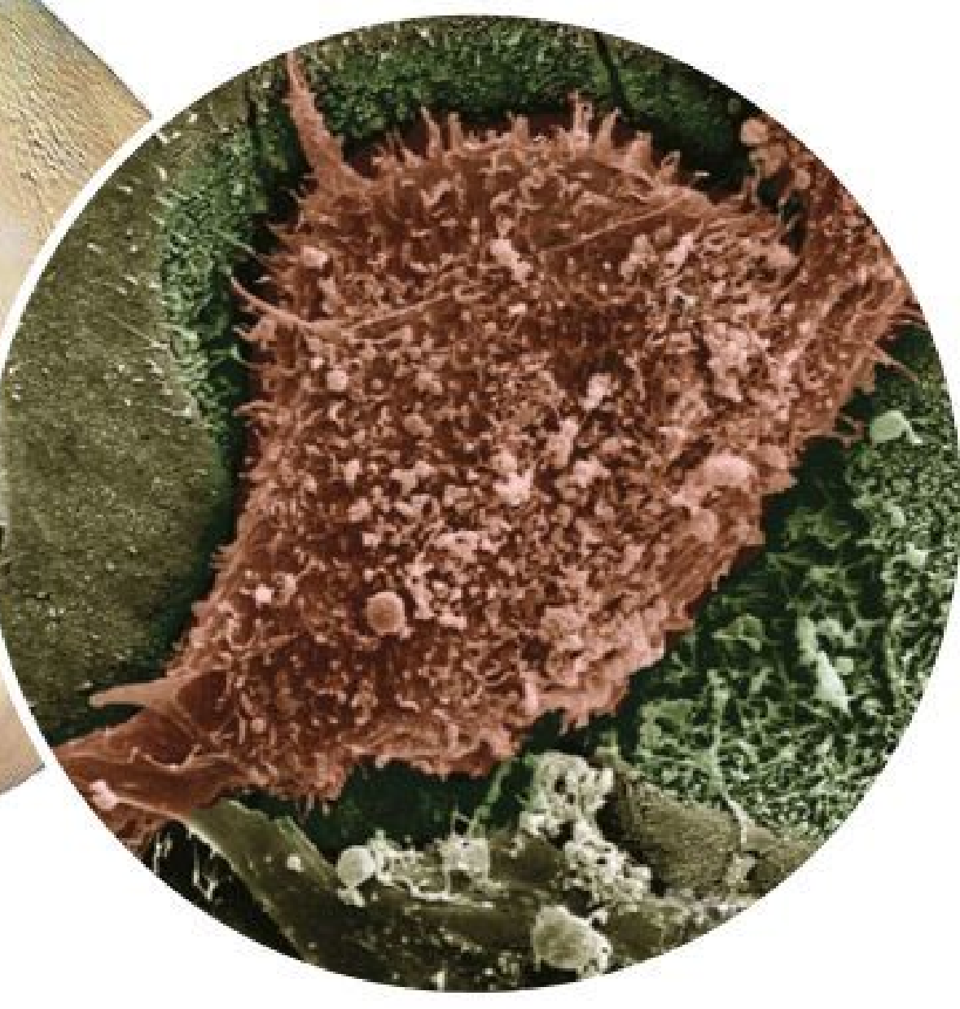
Medullary cavity
The centre of the long bones is filled with yellow bone marrow, containing mainly fat cells.

Diaphysis
The shafts of the long bones are constructed from densely packed compact bone.

Articular cartilage
The end surfaces of the bones are covered in thick, slippery cartilage, preventing wear at the joints.

Epiphysis
The ends of the long bones act as shock absorbers, with a casing of tough compact bone supported by a spongy core.

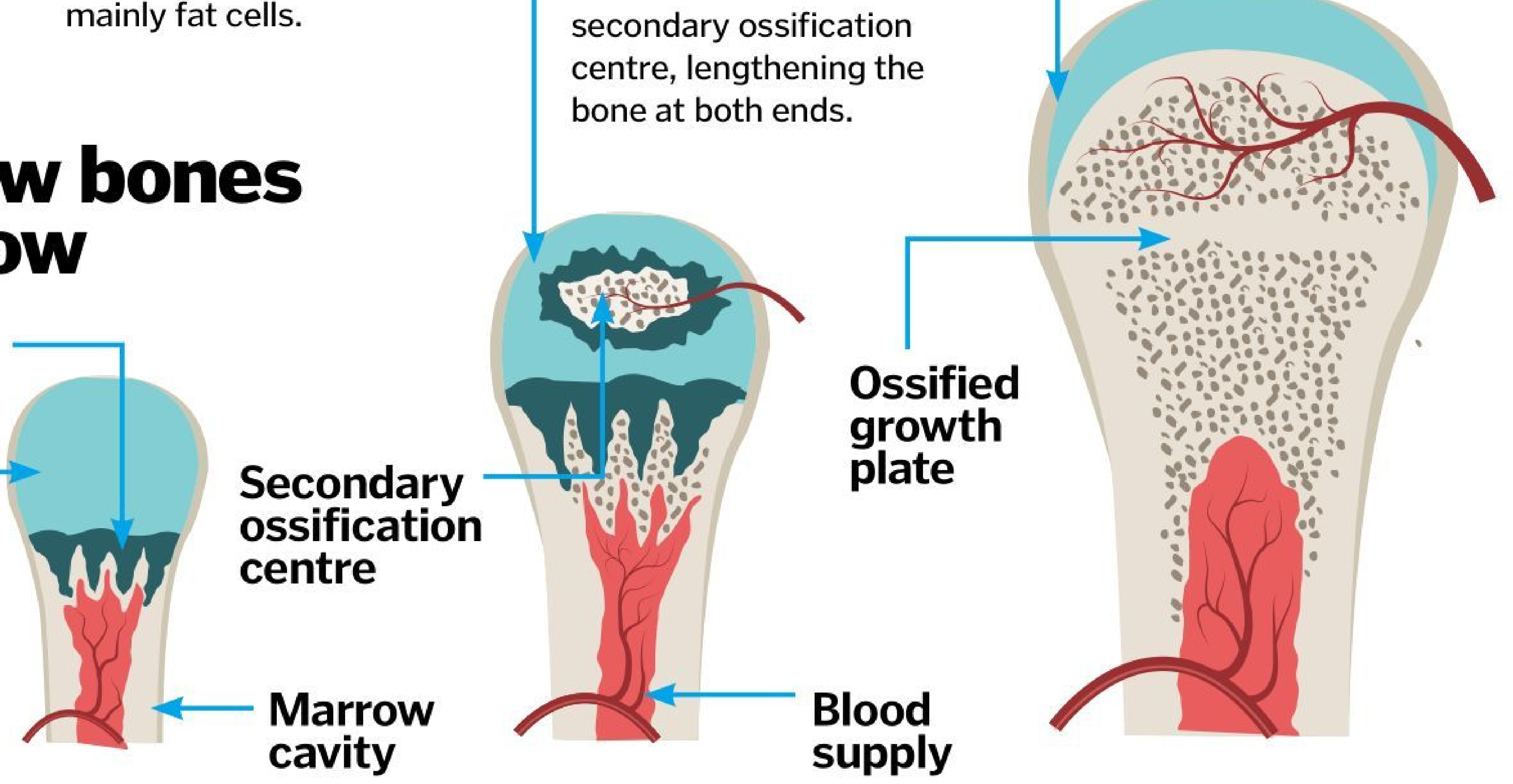
Periosteum
The outside of the bone is covered in a layer of connective tissue, containing cells involved in growth and repair.



BELOW Cells known as osteoclasts constantly remodel the surface of bone

Spongy bone has a characteristic honeycomb structure

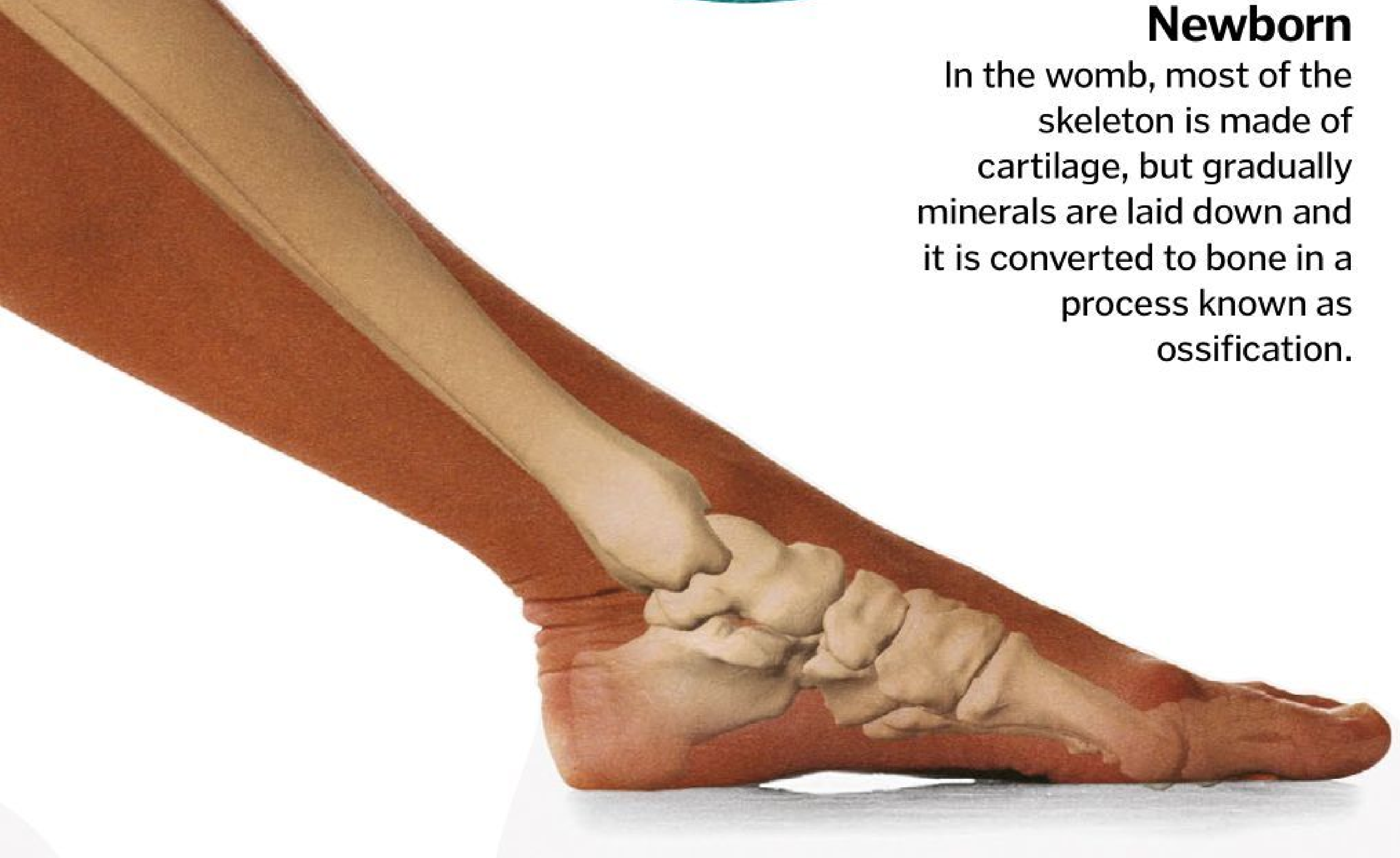
How bones grow



Newborn
In the womb, most of the skeleton is made of cartilage, but gradually minerals are laid down and it is converted to bone in a process known as ossification.

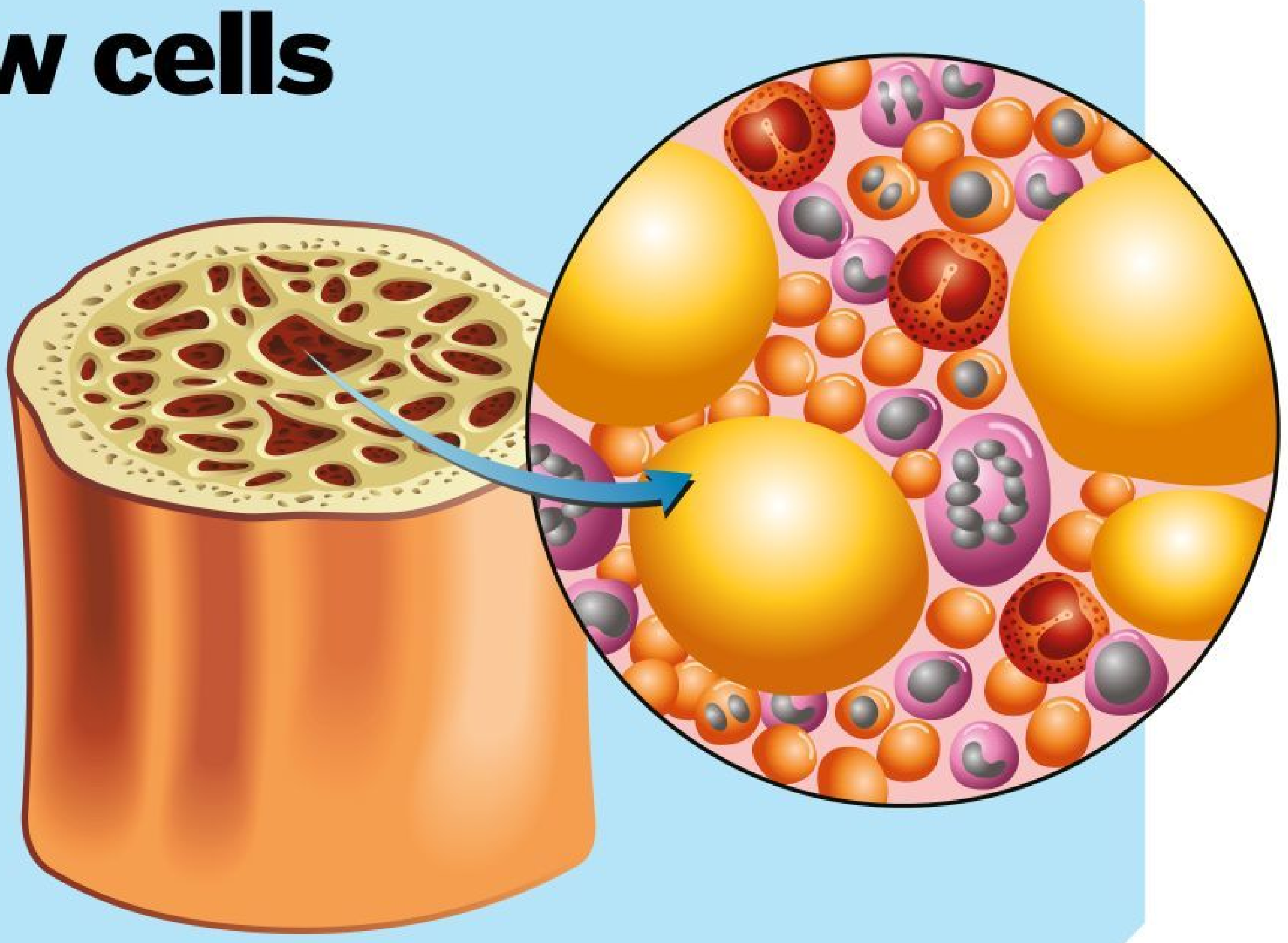
Child
Cartilage continues to form at the growth plates, and calcium salts are added at the secondary ossification centre, lengthening the bone at both ends.

Adult
The growth plate itself is turned to bone, and stops producing cartilage, preventing the bones from lengthening any further.



Bone marrow cells

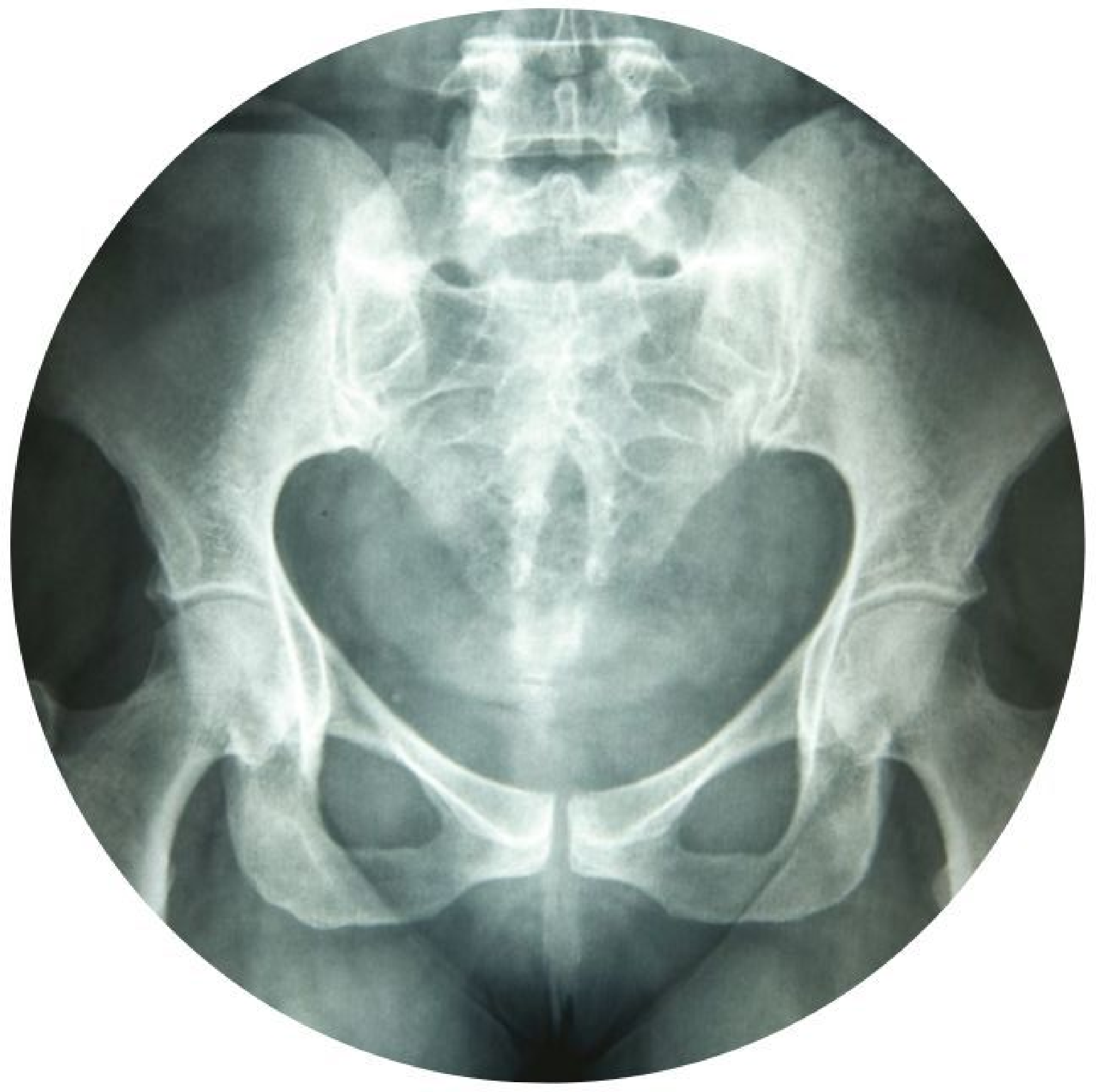
There are two types of bone marrow in the human body; yellow marrow is found in the shafts of the long bones, like the femur, and red marrow is mainly found in the flat bones, like the ribs. Yellow marrow is mostly made up of large fat cells, whilst red marrow contains stem cells. These are capable of producing most of the cells of the blood and immune system, and concealed within the bones are many immature cells in the process of development.



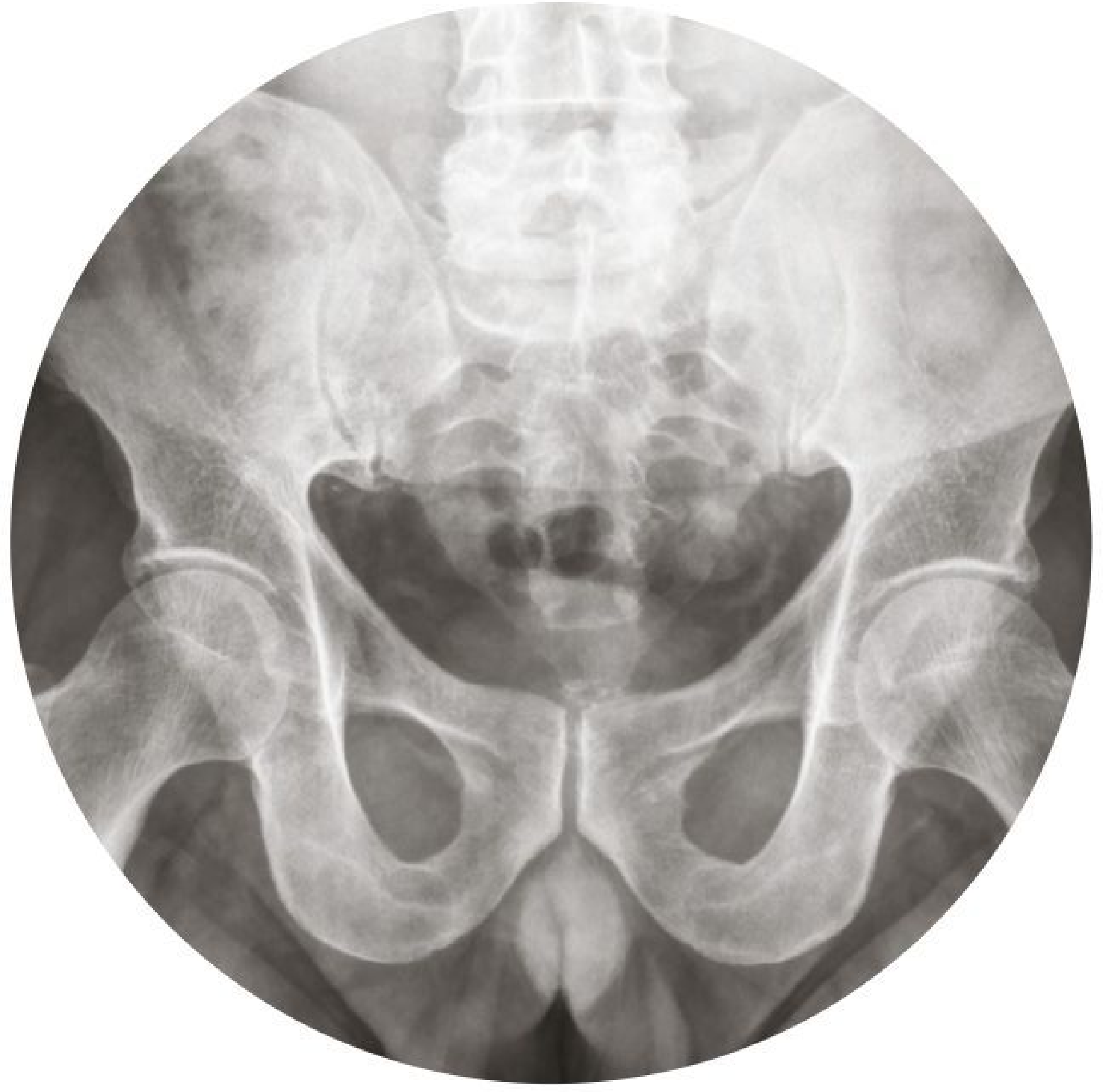
Skeletal system

Get to know the bones in your body with our guide to the human skeleton

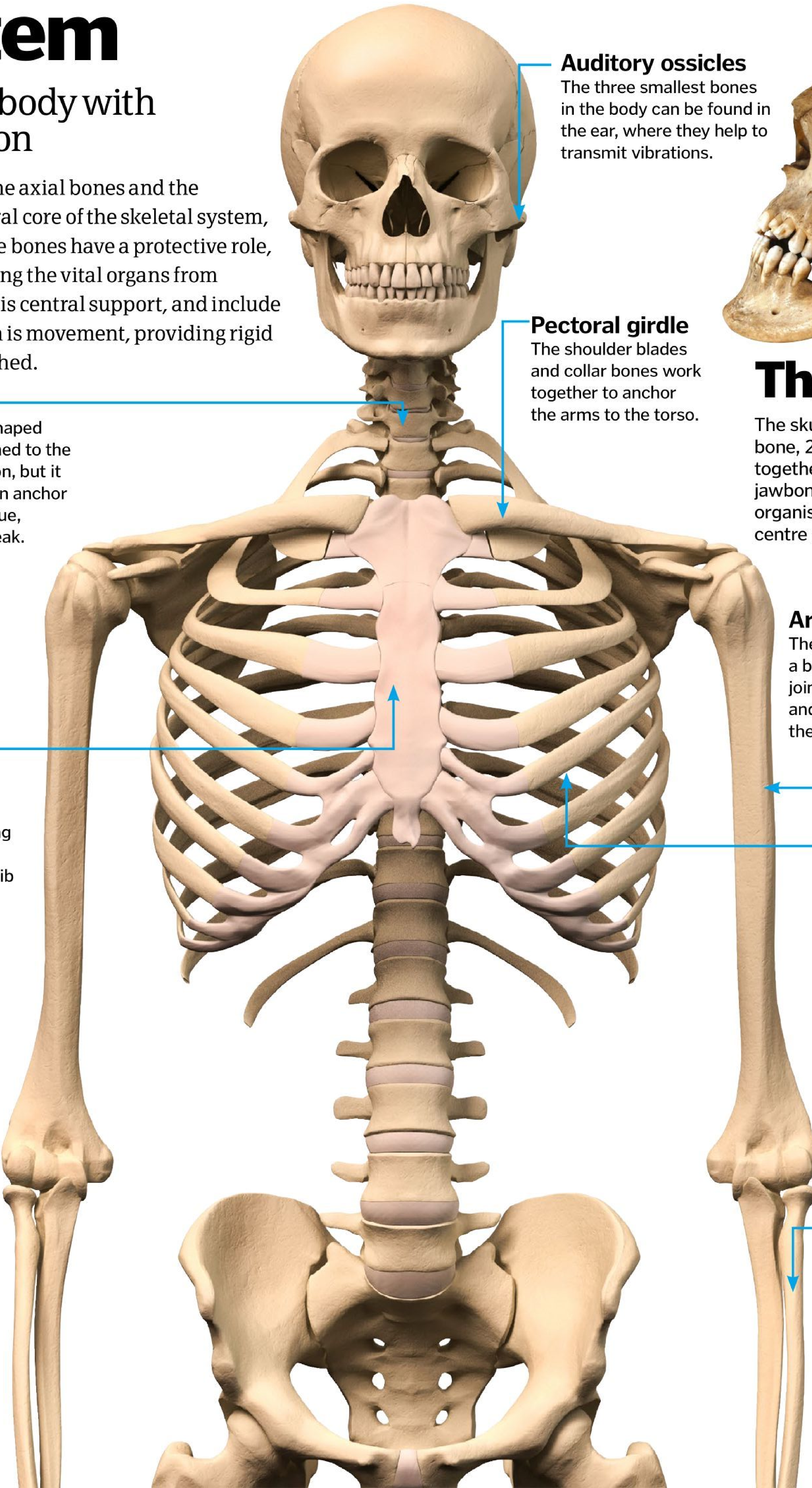
There are two major parts to the human skeleton: the axial bones and the appendicular bones. The axial bones form the central core of the skeletal system, including the skull, spine, rib cage and pelvis. These bones have a protective role, supporting the central nervous system and protecting the vital organs from damage. The appendicular bones are attached to this central support, and include the bones of the arms and legs. Their major function is movement, providing rigid jointed structures onto which the muscles are attached.



ABOVE Females have a larger opening inside the pelvis, aiding childbirth



ABOVE The male pelvis is relatively narrow and the opening is heart-shaped



Hyoid
This horseshoe-shaped bone is not attached to the rest of the skeleton, but it helps to provide an anchor point for the tongue, enabling us to speak.

Sternum
The ribs are anchored to the sternum by cartilage, providing a flexible linkage and allowing the rib cage to contract and expand.

Auditory ossicles
The three smallest bones in the body can be found in the ear, where they help to transmit vibrations.

Pectoral girdle
The shoulder blades and collar bones work together to anchor the arms to the torso.

Arm
The humerus makes a ball-and-socket joint at the shoulder, and a hinge joint at the elbow.

Ribs
Most people have 12 pairs of ribs that, together with the spinal column and sternum, form a protective cage around the heart and lungs.

Forearm
The two bones of the forearm split the load; the ulna bears weight near the elbow, and the radius bears weight near the wrist.

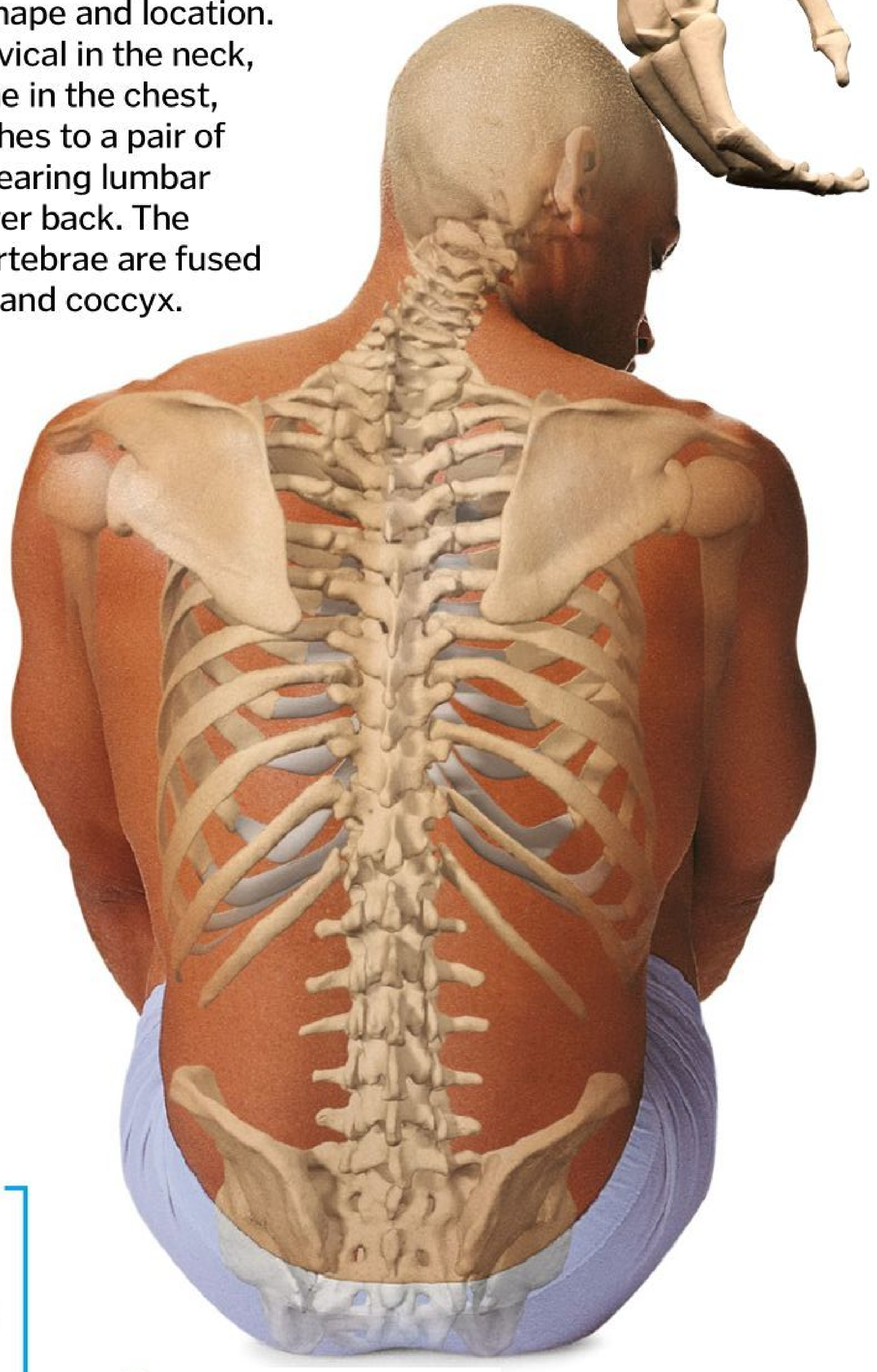
The skull

The skull is constructed out of 22 plates of flat bone, 21 of which are permanently fused together. The other is the mandible, or jawbone. They are made from a thick layer of organised cortical bone, sandwiched around a centre of spongy bone.

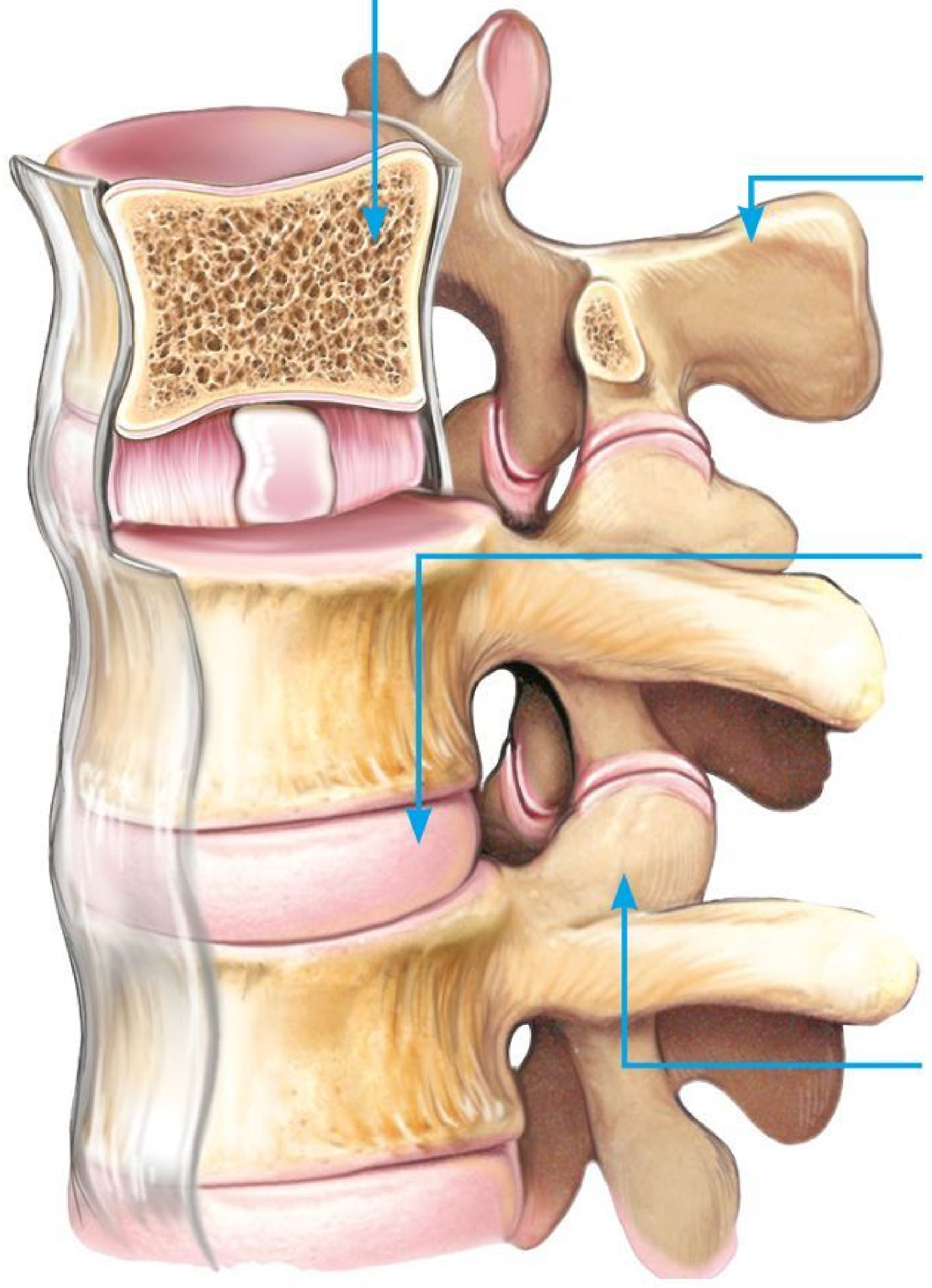
10
years to replace your entire skeleton

The spine

There are 33 vertebrae in the spinal column, divided into categories according to their shape and location. There are seven cervical in the neck, 12 thoracic vertebrae in the chest, each of which attaches to a pair of ribs, and five load-bearing lumbar vertebrae in the lower back. The remainder of the vertebrae are fused to form the sacrum and coccyx.



33
vertebrae in the spine

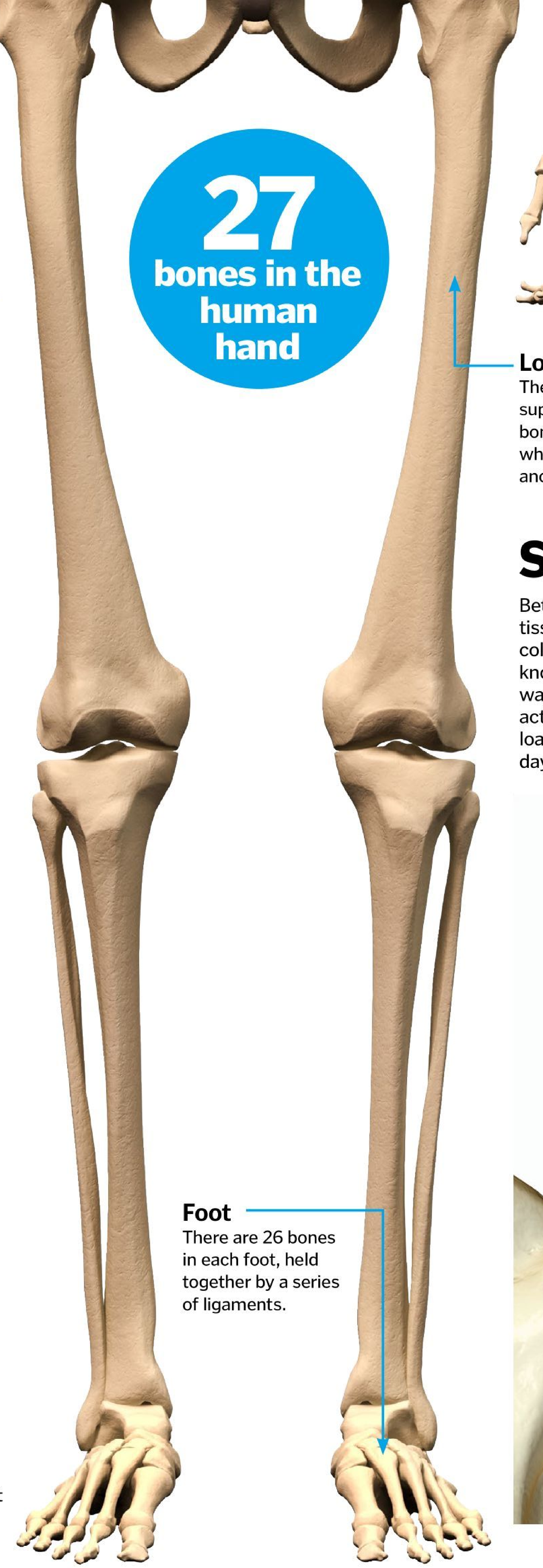


Vertebral body
Each vertebra contains a core of spongy bone and red bone marrow.

Spinous process
Muscles attach to protruding bone at the back of each vertebra.

Intervertebral disk
A disk of cartilage between each vertebra provides cushioning and protection.

Articular process
Each vertebra has four articular processes, connected to the adjacent vertebrae by ligaments.



27
bones in the human hand

Wrist, hand and fingers
There are 27 bones in each hand, eight of which make up the wrist.

Lower limb
The weight of the body is supported by the femur (thigh bone) and the tibia (shin bone), while the fibula is involved in anchoring the muscles of the foot.

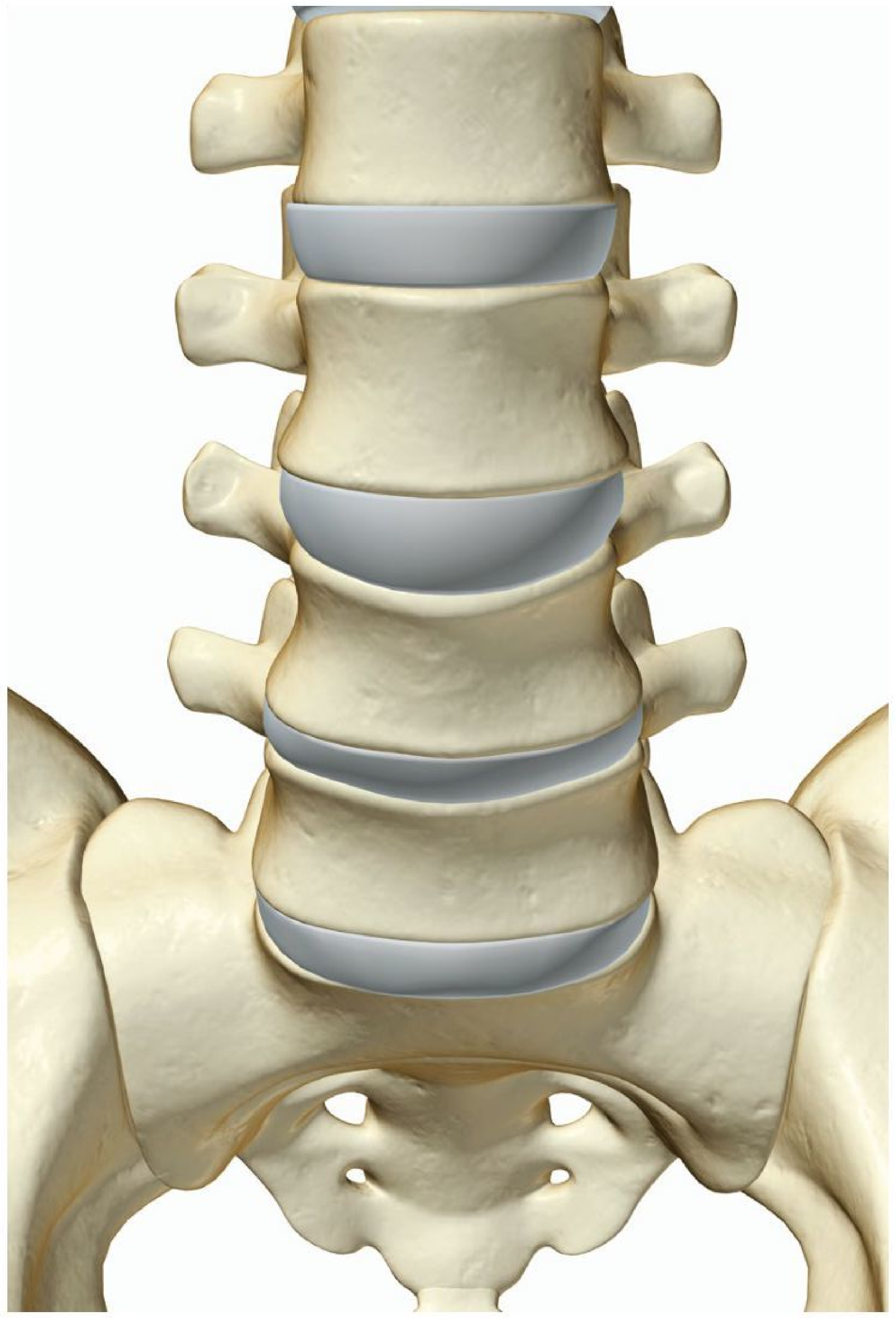
Foot
There are 26 bones in each foot, held together by a series of ligaments.

Learn more

Get your own giant 1.3m high poster to help explore every bone in the human skeleton – great for home and schools. Drawn to scale and anatomically detailed by leading medical artist, Joanna Culley. A matching muscle poster is also available, all from www.uAnatomy.com.

Shock absorbers

Between the vertebrae of the spine are disks of a springy tissue known as fibrocartilage, made up of long chains of collagen and bound together by a gel of sugary proteins, known as glycoproteins. These have a strong affinity for water, so as a result, the entire tissue is filled with fluid. It acts like suspension, compressing and deforming under load and protecting the bones from the stress of day-to-day impact.



Joints

For individual bones to function together, they must be linked by joints

Some bones, like those in the skull, do not need to move, and are permanently fused together with mineral sutures. These are known as fixed joints and provide maximum stability.

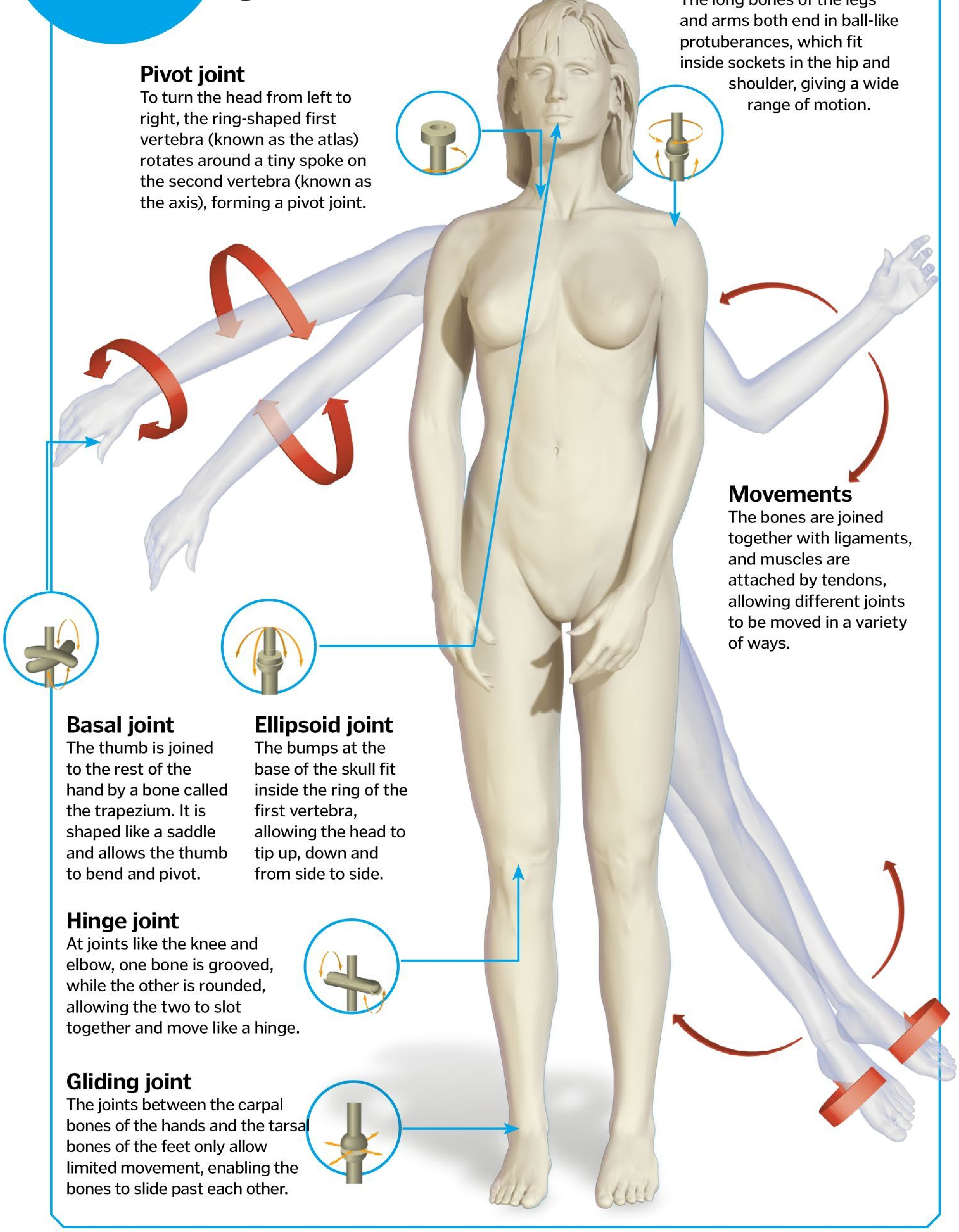
However, most bones need flexible linkages. In some parts of the skeleton, partial flexibility is sufficient, so all that the bones require is a little cushioning to prevent rubbing. The bones are joined by a rigid gel-like tissue known as cartilage, which allows for a small range of compression and stretching. These types of joints are used where the ribs meet the sternum, to provide flexibility when breathing, and between the stacked vertebrae of the spinal column, allowing it to bend and flex without crushing the spinal cord.

Most joints require a larger range of movement. Covering the ends of the bones in cartilage provides shock absorption, but for them to move freely in a socket, the cartilage must be lubricated to make it slippery and wear-proof. At synovial joints, the ends of the two bones are encased in a capsule, covered on the inside by a synovial membrane, which fills the joint with synovial fluid, allowing the bones to slide smoothly past one another.

There are different types of synovial joint, each with a different range of motion. Ball-and-socket joints are used at the shoulder and hip, and provide a wide range of motion, allowing the curved surface at the top end of each limb to slide inside a cartilage covered cup. The knees and elbows have hinge joints, which interlock in one plane, allowing the joint to open and close. For areas that need to be flexible, but do not need to move freely, such as the feet, gliding joints allow the bones to slide small distances without rubbing.

15%
body weight contributed by the skeleton

Bone joints



Ball-and-socket joint
The long bones of the legs and arms both end in ball-like protuberances, which fit inside sockets in the hip and shoulder, giving a wide range of motion.

Pivot joint
To turn the head from left to right, the ring-shaped first vertebra (known as the atlas) rotates around a tiny spoke on the second vertebra (known as the axis), forming a pivot joint.

Movements
The bones are joined together with ligaments, and muscles are attached by tendons, allowing different joints to be moved in a variety of ways.

Basal joint
The thumb is joined to the rest of the hand by a bone called the trapezium. It is shaped like a saddle and allows the thumb to bend and pivot.

Ellipsoid joint
The bumps at the base of the skull fit inside the ring of the first vertebra, allowing the head to tip up, down and from side to side.

Hinge joint
At joints like the knee and elbow, one bone is grooved, while the other is rounded, allowing the two to slot together and move like a hinge.

Gliding joint
The joints between the carpal bones of the hands and the tarsal bones of the feet only allow limited movement, enabling the bones to slide past each other.

Hypermobility

Some people have particularly flexible joints, so have a much larger range of motion than others. This is sometimes known as being 'double jointed.' It is thought to result from a combination of factors, including the structure of the collagen in the joints, the shape of the end of the bones, and the tone of the muscles around the joint.

Mobile

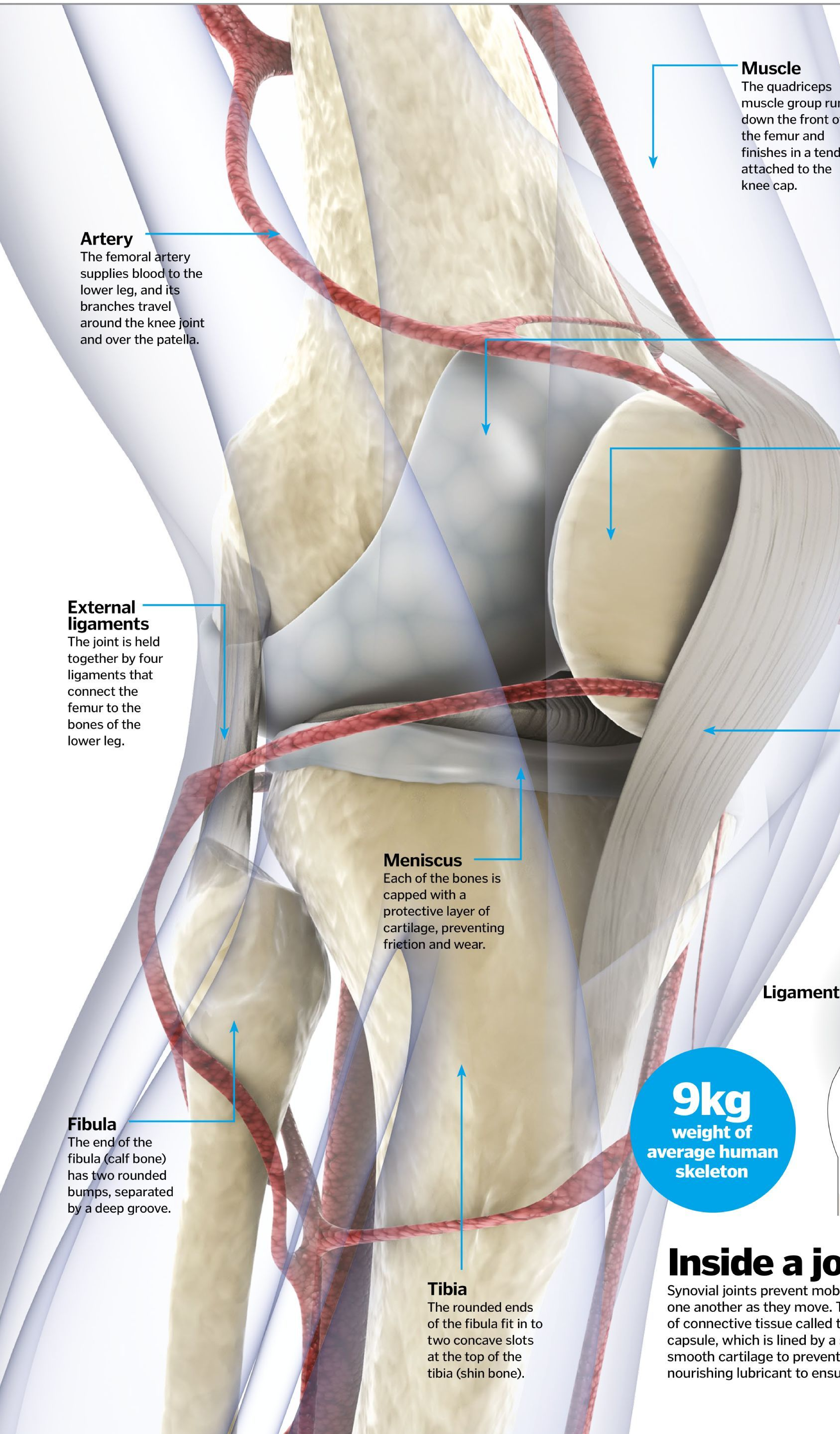
The synovial joints are the most mobile in the human body. The ends of the bones are linked by a capsule, which contains a fluid lubricant, allowing the bones to slide past one another as they move. Synovial joints come in different types, including ball-and-socket, hinge, and gliding, and they are the most common type of joint in the body.

Semimobile

Cartilaginous joints do not allow free motion, but provide cushioning for smaller movements. Instead of a lubricated capsule, the bones are joined by fibrous or hyaline cartilage. The linkage provides less flexibility than a synovial joint, but acts as a shock absorber, so the bones can move apart and together over small distances.

Fixed

Some bones do not need to move relative to one another, so instead of a flexible joint, they are permanently fused. The best example is the cranium, which starts out as separate pieces, allowing the foetal head to change shape to fit through the birth canal, and fuses after birth to encase the brain in a solid protective skull.



Muscle
The quadriceps muscle group runs down the front of the femur and finishes in a tendon attached to the knee cap.

Artery
The femoral artery supplies blood to the lower leg, and its branches travel around the knee joint and over the patella.

Synovial membrane
The membrane surrounding the interior of the joint produces a lubricant called synovial fluid.

Knee cap
The patella prevents the tendons at the front of the leg from wearing away at the joint.

External ligaments
The joint is held together by four ligaments that connect the femur to the bones of the lower leg.

Patellar ligament
The patellar ligament connects the kneecap to both the quadriceps in the thigh and the tibia in the lower leg.

Meniscus
Each of the bones is capped with a protective layer of cartilage, preventing friction and wear.

Fibula
The end of the fibula (calf bone) has two rounded bumps, separated by a deep groove.

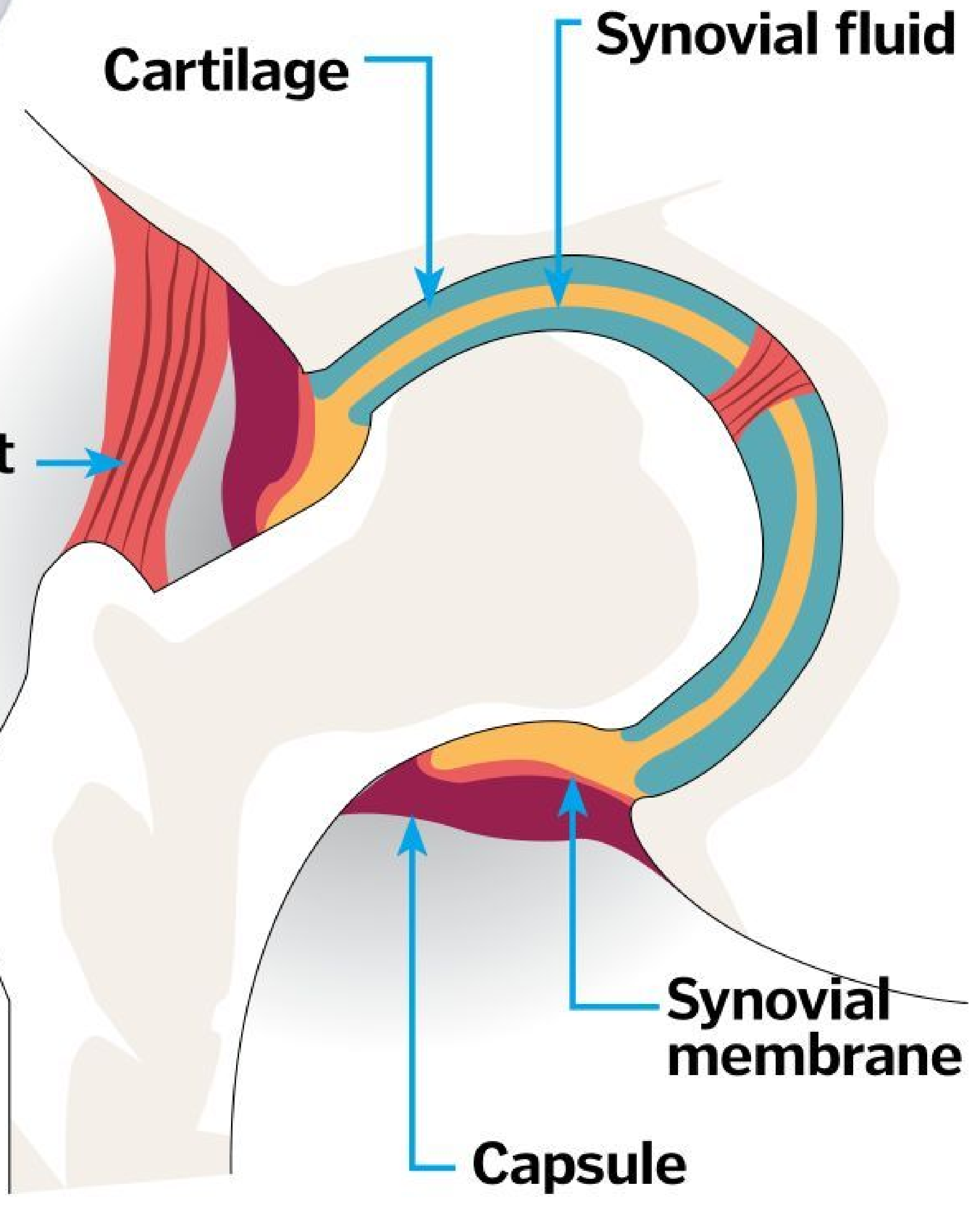
Tibia
The rounded ends of the fibula fit in to two concave slots at the top of the tibia (shin bone).

Why our joints crack

The synovial fluid used to lubricate the joints contains dissolved gasses. The fluid is sealed within a capsule, so if the joint is stretched, the capsule also stretches, creating a vacuum as the pressure changes, and pulling the gas out of solution and into a bubble, which pops, producing a cracking sound.

300+
bones in a newborn baby

9kg
weight of average human skeleton



Inside a joint

Synovial joints prevent mobile areas of the skeleton from grinding against one another as they move. The two bones are loosely connected by strips of connective tissue called tendons, and the two ends are encased in a capsule, which is lined by a synovial membrane. The bones are covered in smooth cartilage to prevent abrasion and the membrane produces a nourishing lubricant to ensure the joint moves smoothly.

© Thinkstock; Sol 90; Alamy; Corbis; Dreamstime; Medical Artist; DK Images

Inside a blood vessel

Discover what happens every time your heart beats

Inside your body there is a vast network of blood vessels that, if laid end to end, could easily wrap twice around the Earth. They are an important part of your circulatory system, carrying the equivalent of more than 14,000 litres of blood around your body every day to transport vital nutrients to where they're needed.

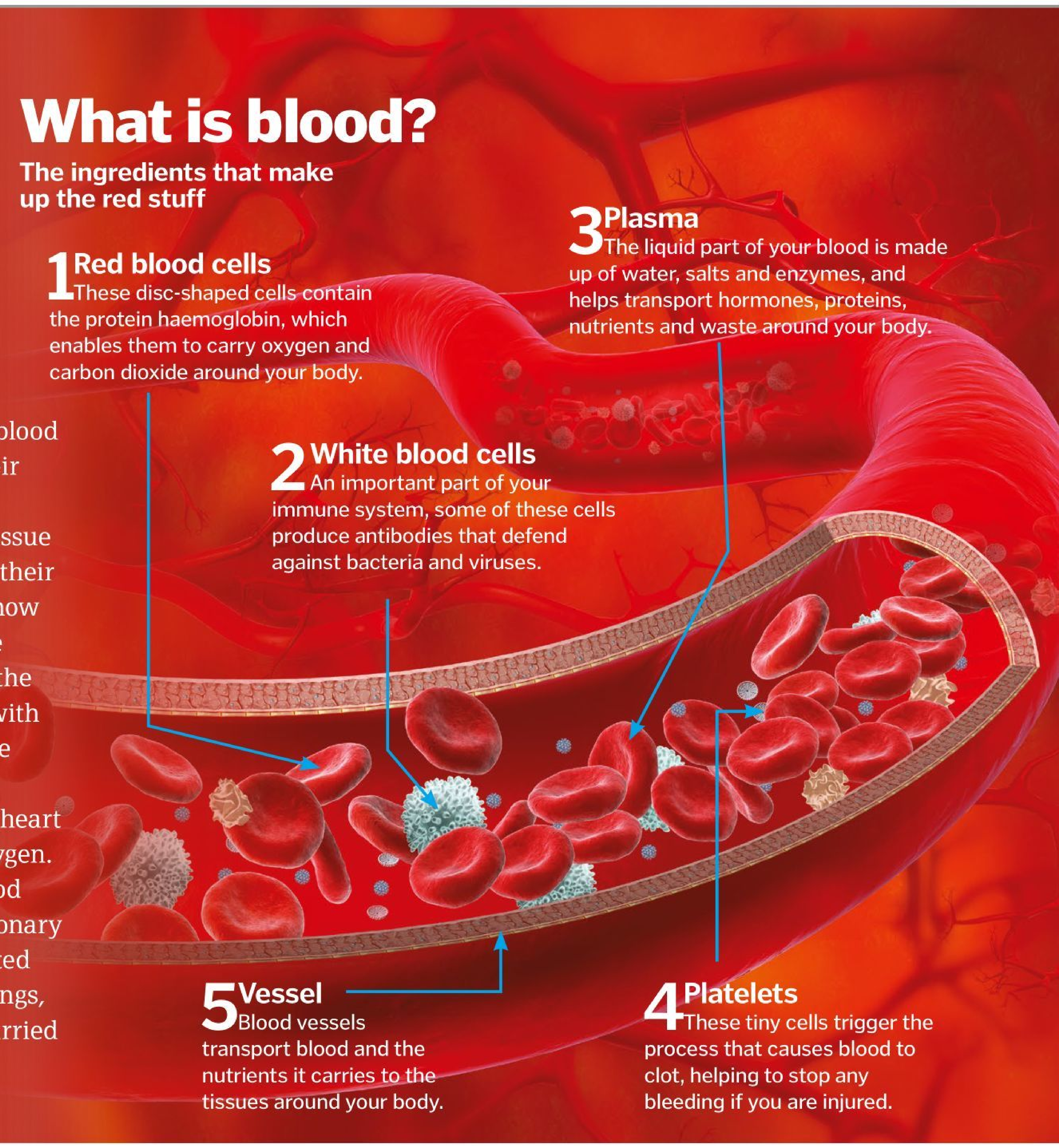
There are five main types of blood vessel. In general, arteries carry oxygenated blood away from the heart and have special elastic fibres in their walls to help squeeze it along when the heart muscle relaxes. The arteries then branch off into smaller arterioles, which pass the blood into the capillaries, tiny blood vessels that transport nutrients from the blood into the body's tissues via their very thin walls.

As well as nourishing the tissue cells, capillaries also remove their waste products, passing the now deoxygenated blood on to the venules. These vessels drain the blood into the veins, which, with the help of valves that stop the blood flowing in the reverse direction, carry it back to the heart where it can pick up more oxygen.

In contrast to the other blood vessels in the body, the pulmonary artery transports deoxygenated blood from the heart to the lungs, where it is oxygenated and carried back to the heart via the pulmonary veins.

What is blood?

The ingredients that make up the red stuff



1 Red blood cells These disc-shaped cells contain the protein haemoglobin, which enables them to carry oxygen and carbon dioxide around your body.

2 White blood cells An important part of your immune system, some of these cells produce antibodies that defend against bacteria and viruses.

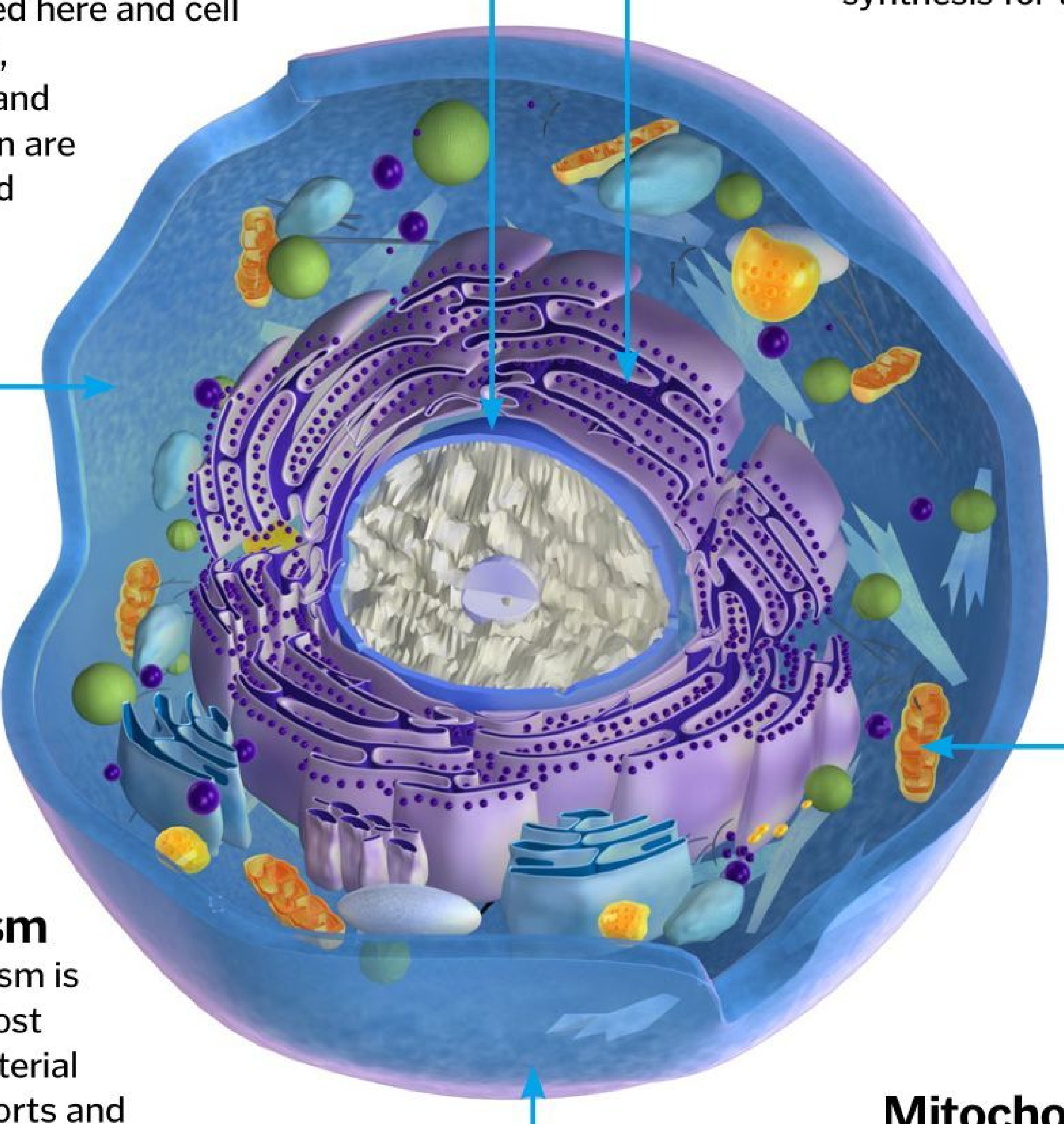
3 Plasma The liquid part of your blood is made up of water, salts and enzymes, and helps transport hormones, proteins, nutrients and waste around your body.

4 Platelets These tiny cells trigger the process that causes blood to clot, helping to stop any bleeding if you are injured.

5 Vessel Blood vessels transport blood and the nutrients it carries to the tissues around your body.

Animal cells

A typical, non-specialised animal cell



Nucleus The nucleus is often referred to as the brain of the cell. DNA is stored here and cell metabolism, movement and reproduction are all controlled from here.

Ribosomes Ribosomes are spherical bodies composed of RNA and protein enzymes which are the site of protein synthesis for the cell.

Cytoplasm The cytoplasm is a thick, almost jelly-like material which supports and protects organelles of the cell.

Mitochondria Mitochondria are small, bean-shaped organelles which release chemical energy for the cell by processing glucose that is provided for, or produced by, the cell.

Cell membrane Present in animal and plant cells, this acts as a boundary layer to protect the cell from unwanted chemicals.

How cells work

The building blocks of life explained

Cells are the building blocks of all living organisms. Individual cells are classified as living things, and there are millions of organisms which are unicellular across the planet.

As they are living units, cells consequently need energy, and therefore respire to survive. Parts of the cell, called organelles, work like organs of a body. Energy for the cell to process can be provided by the cell, such as through photosynthesis in plants, or absorbed into the cell through cell membranes and then processed within it by the mitochondrion. Single cells operate like this, and there are billions of unicellular organisms that survive independently or within multicellular organisms. These single cell organisms are generally prokaryotic cells, which are much smaller and have fewer organelles, most importantly lacking a nucleus. Multicellular organisms are primarily made up of eukaryotic cells which are more complex and can therefore specialise so the organism can become more complex. They do this by grouping together to form tissues, which then group to form organs within the organism.

Cells reproduce to replace old, damaged cells in an organism, to allow growth of a new individual. In unicellular organisms, cell reproduction is obviously the only way a population will grow. Prokaryotes favour binary fission, where all genetic information is doubled and then the cell divides into two new, identical cells. Eukaryote cells use either mitosis, which results in two identical organisms or cells, or meiosis, which results in each new cell having half the number of chromosomes of the original cell.

The heart – a vital organ

Your heart is a turbocharged double-pumping muscle that beats more than 40 million times every year

Not only does your heart do amazing things, it does so tirelessly, from the moment you're born (actually, even a bit before then) to the instant that you die. It weighs somewhere between eight and 12 ounces – slightly more if you're male, less if you're female. Its sole purpose is to push blood through your circulatory system, providing crucial oxygen and other nutrients to all your organs.

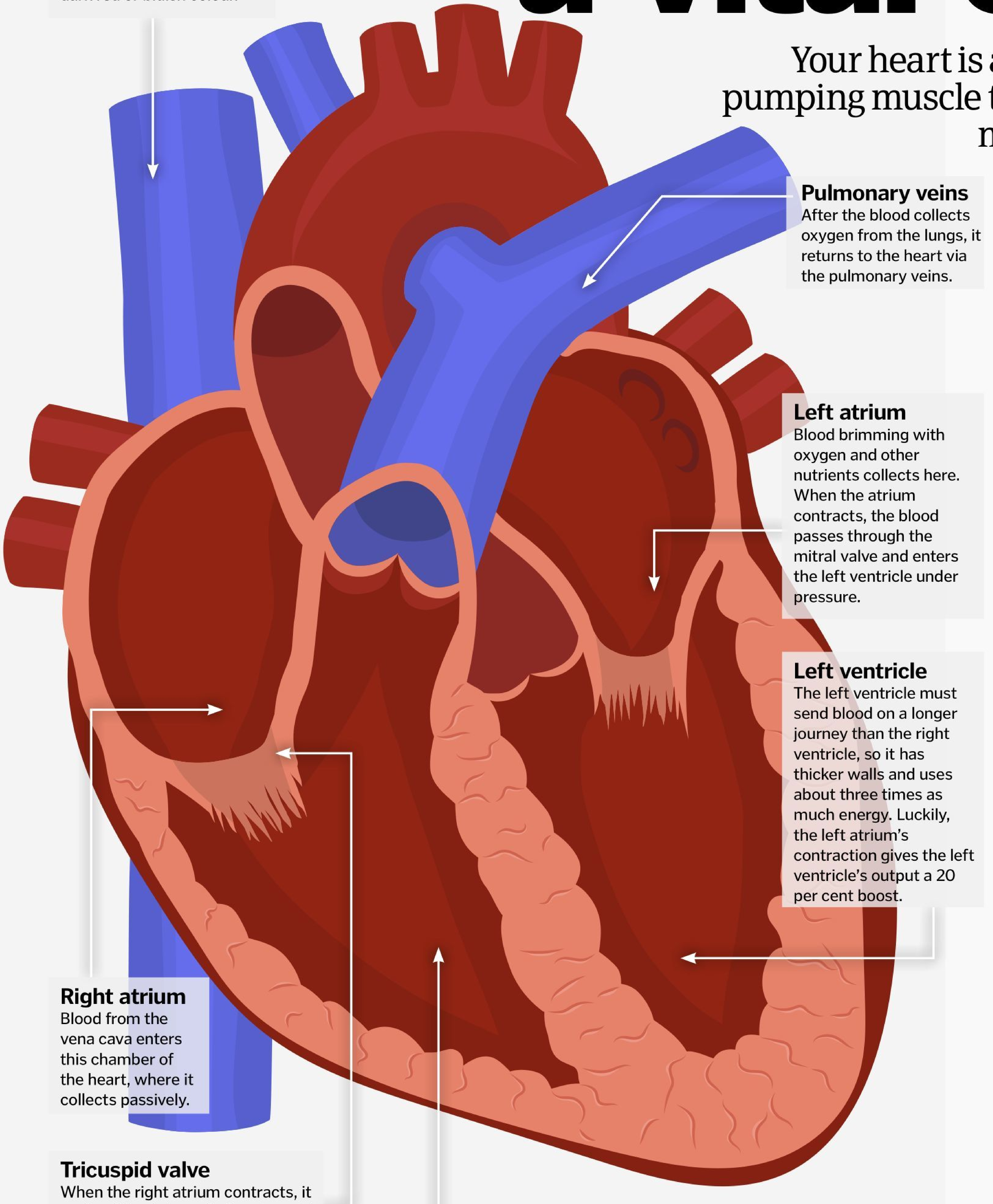
The heart is considered a double pump because the right half sends 'used' blood to your lungs. There, the blood drops off a load of carbon dioxide and picks up some fresh oxygen, which you have helpfully provided by breathing. Then the oxygenated blood returns to the left half of the heart. This 'heart-to-lungs-to-heart-again' trip is known as pulmonary circulation. The left side of the heart then pumps this oxygenated blood to every organ in your body other than your lungs. Your brain, your skin, the muscles in your thigh, your spleen – they all get blood (and therefore oxygen) by virtue of your beating heart.

Even the heart itself gets blood, via a special set of veins and arteries known as the coronary system. The myocardial muscle within the wall of the heart needs oxygen and other nutrients to keep beating. Unfortunately, the coronary arteries that do this job are very narrow, between 1.7 and 2.2 millimetres in diameter. If they become clogged with cholesterol or other fatty deposits, the heart stops working.

Of course, the relatively simple concept of the double pump is fairly complex in practice. A series of valves control blood flow to the heart's four chambers, allow for the build-up of enough blood pressure to get the job done, and direct the blood to the correct veins and arteries.

What's inside your heart

Find out how your heart pumps blood around your body



Superior and inferior vena cava
These large veins carry blood back to the heart from organs above and below the heart, respectively. This blood has already been stripped of its oxygen supply, and thus is a dark red or bluish colour.

Pulmonary veins
After the blood collects oxygen from the lungs, it returns to the heart via the pulmonary veins.

Left atrium
Blood brimming with oxygen and other nutrients collects here. When the atrium contracts, the blood passes through the mitral valve and enters the left ventricle under pressure.

Left ventricle
The left ventricle must send blood on a longer journey than the right ventricle, so it has thicker walls and uses about three times as much energy. Luckily, the left atrium's contraction gives the left ventricle's output a 20 per cent boost.

Right atrium
Blood from the vena cava enters this chamber of the heart, where it collects passively.

Tricuspid valve
When the right atrium contracts, it pushes blood through the tricuspid valve, a one-way valve leading down into the right ventricle.

Right ventricle
Blood enters the right ventricle under pressure from the atrium's contraction, giving it a boost much like the turbocharger in a high-performance car. The ventricle contracts and pumps blood through the pulmonary valve, into the pulmonary artery and toward the lungs.

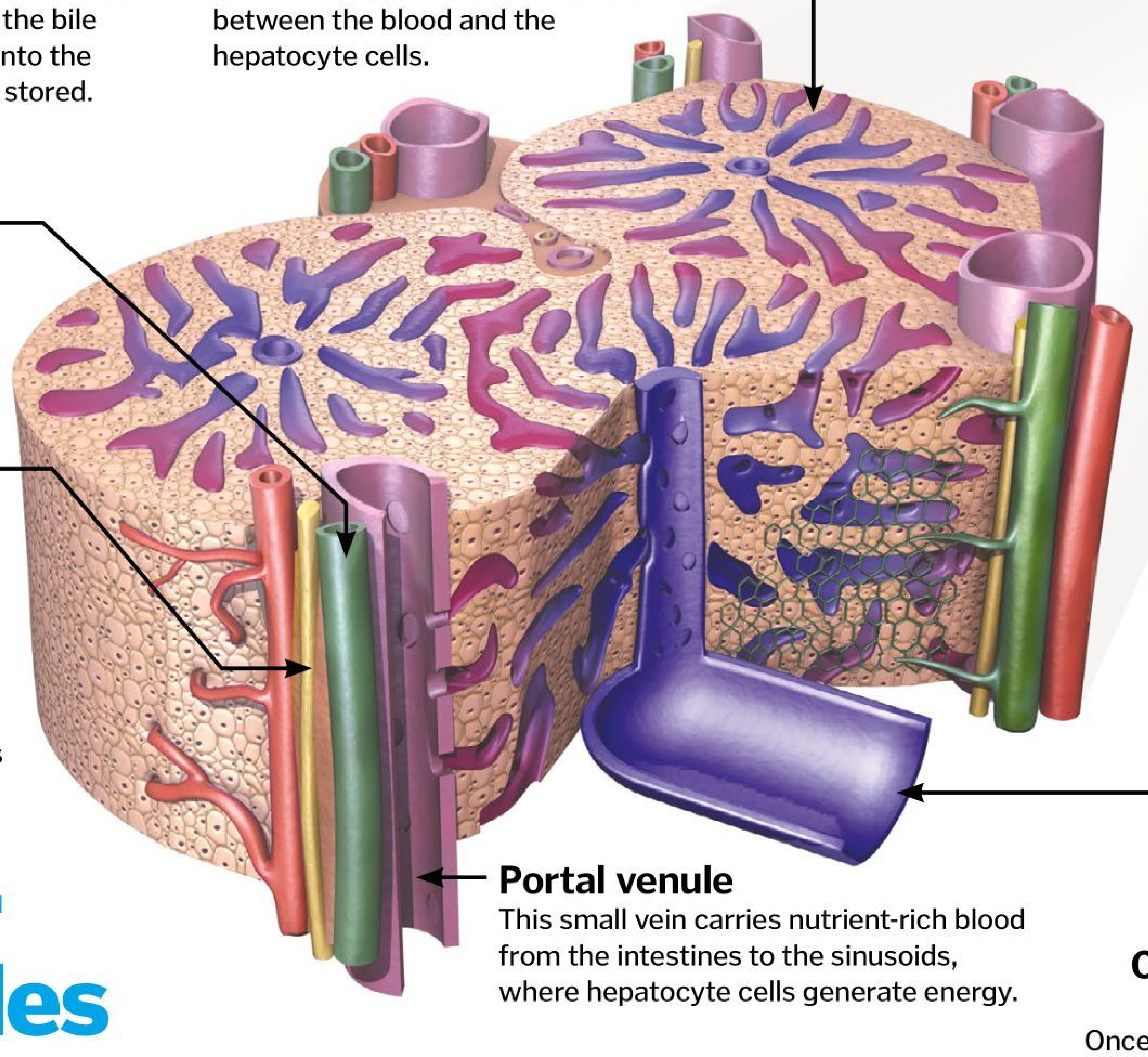
Inside the liver and pancreas

How do these vital organs work together to digest food?

Weighing more than a bag of sugar, the liver is the largest of all the internal organs. It's located mostly in the right side of your abdominal cavity and is capable of holding roughly ten per cent of your body's total blood volume, with around a quarter of your blood supply passing through it every minute.

The liver has many roles in the body, one of which is producing bile, the substance that breaks up fat molecules to aid digestion. Up to one litre of this greenish-yellow liquid is produced and released every day, containing a combination of salts, water, cholesterol and a pigment called bilirubin. Bile travels from the liver to the gallbladder, where it is stored. When a fat-containing food reaches the duodenum (part of the small intestine), the gallbladder is stimulated to secrete this bile, which travels through the bile duct and reaches the duodenum. Here it breaks down complex fat molecules into smaller, circular globules – a process called emulsification. These globules are smaller and have a larger total surface area, making them easier to digest.

The pancreas also plays a role in digestion, as it produces substances that help to break down food. When the stomach and duodenum are stretched by the presence of a meal, the pancreas is triggered to deliver an assortment of enzymes in a cocktail known as pancreatic juice. An enzyme called amylase breaks down starches, while trypsin digests proteins and lipase works on fatty acids.



Bile ducts
Once bile has been made in the liver's hepatocyte cells, it's secreted into the bile ducts and flows into the gallbladder to be stored.

Sinusoids
These small blood vessels provide the place for molecules to transfer between the blood and the hepatocyte cells.

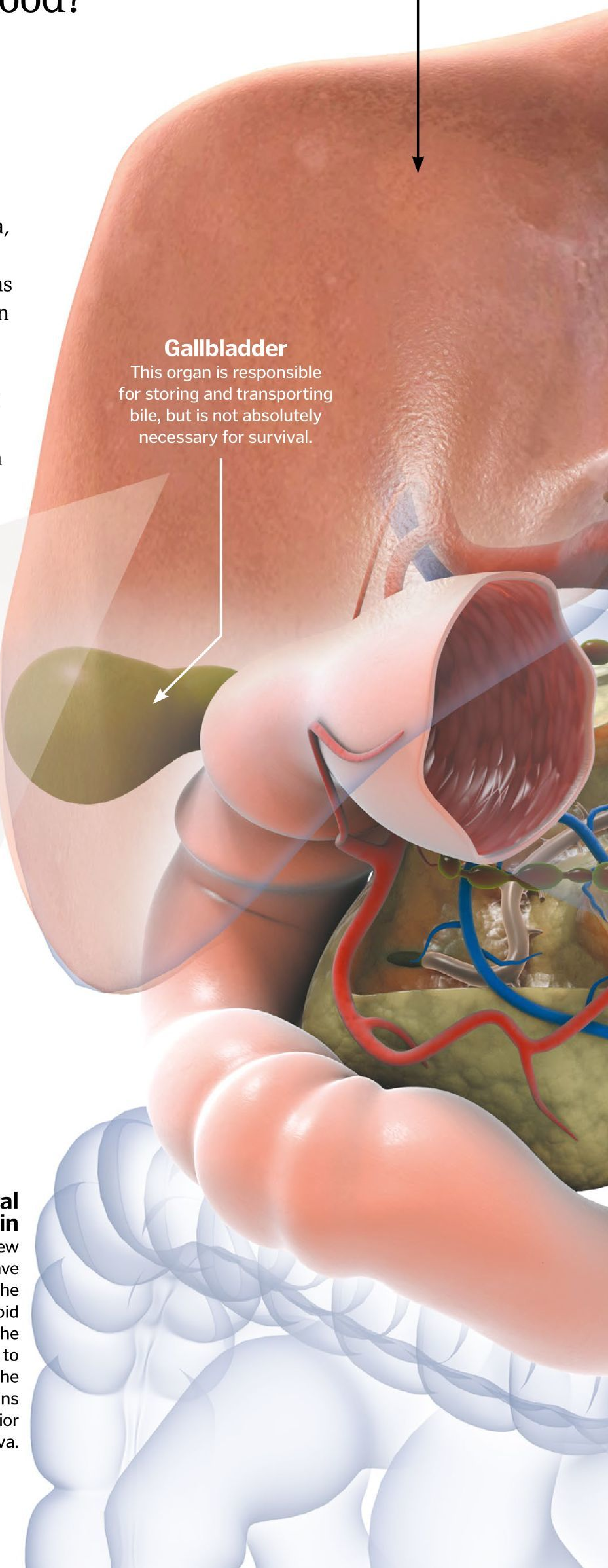
The portal triad
Providing the main entry and exit routes for the liver, the portal venule, bile duct and the hepatic artery are referred to as the portal triad.

Portal venule
This small vein carries nutrient-rich blood from the intestines to the sinusoids, where hepatocyte cells generate energy.

Central vein
Once the new molecules have passed into the sinusoid channels, the blood flows to the heart via the hepatic veins and the inferior vena cava.

Liver lobules

The lobules consist of rows of hepatocytes (liver cells), bile ducts and blood vessels. Roughly 100,000 of these hexagonal-shaped structures sit within the organ, each consisting of a central vein surrounded by six hepatic portal veins and six hepatic arteries. These blood vessels are connected by sinusoids, which are small tubes joining the central vein to the surrounding veins and arteries. The products from digestion are transported in the blood to the sinusoids, where they can be absorbed into the hepatocytes.



Lobes
The liver is split into four lobes: right, left, caudate and quadrate. The right lobe is the largest.

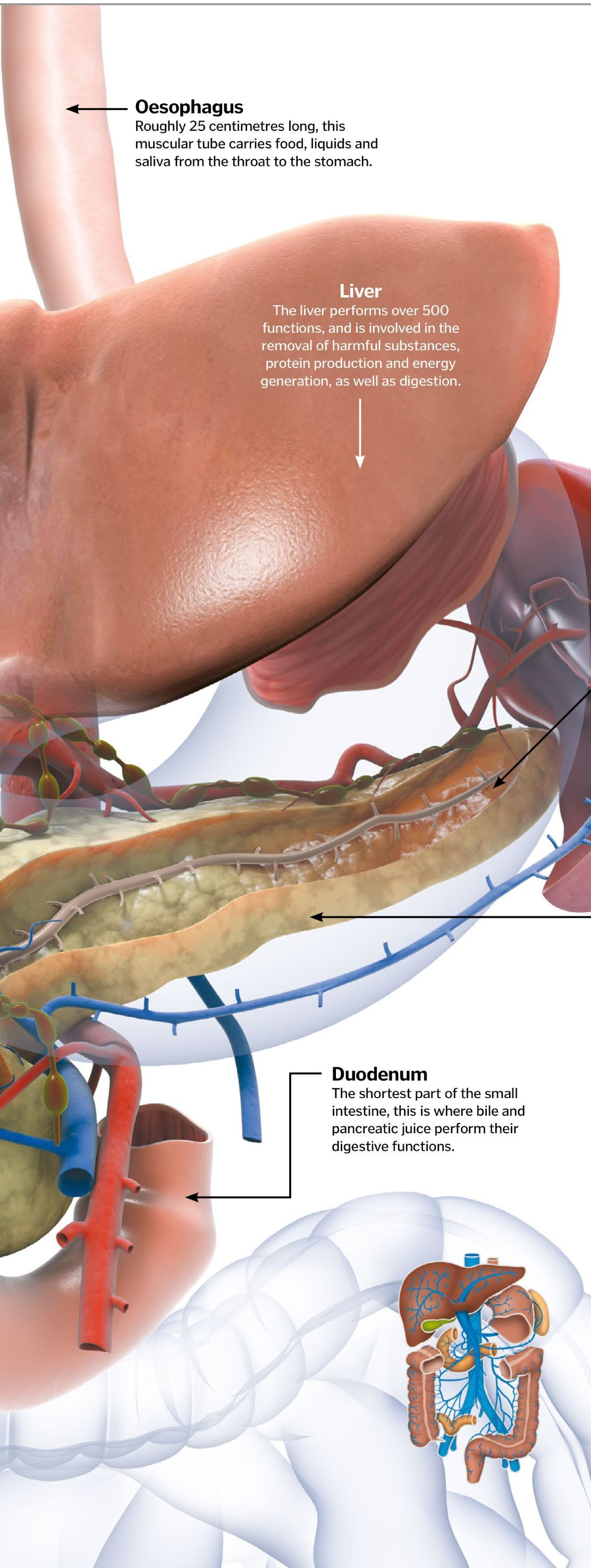
Gallbladder
This organ is responsible for storing and transporting bile, but is not absolutely necessary for survival.

DID YOU KNOW? *The liver is able to regenerate itself – up to half of it can be removed and will eventually grow back*

Liver metabolism

Metabolism is more than just the body's way of breaking down food into the energy we need to survive – it's the conversion of one chemical compound into another. In the liver, cells called hepatocytes perform many key metabolic tasks. These cells work to convert proteins, fats and carbohydrates into molecules that the body can use or store. For example, much of the glucose that passes through the liver is absorbed by the hepatocytes, which stockpile it as a larger molecule, glycogen. This is easier to store and can be quickly turned back into glucose when it's required.

The liver is responsible for maintaining the body's blood glucose levels. If there is no glucose available, the liver breaks down the stored glycogen instead. By absorbing and releasing glucose, the hepatocytes help to maintain a balance in the body, preventing dangerous spikes or drops in your blood sugar level.



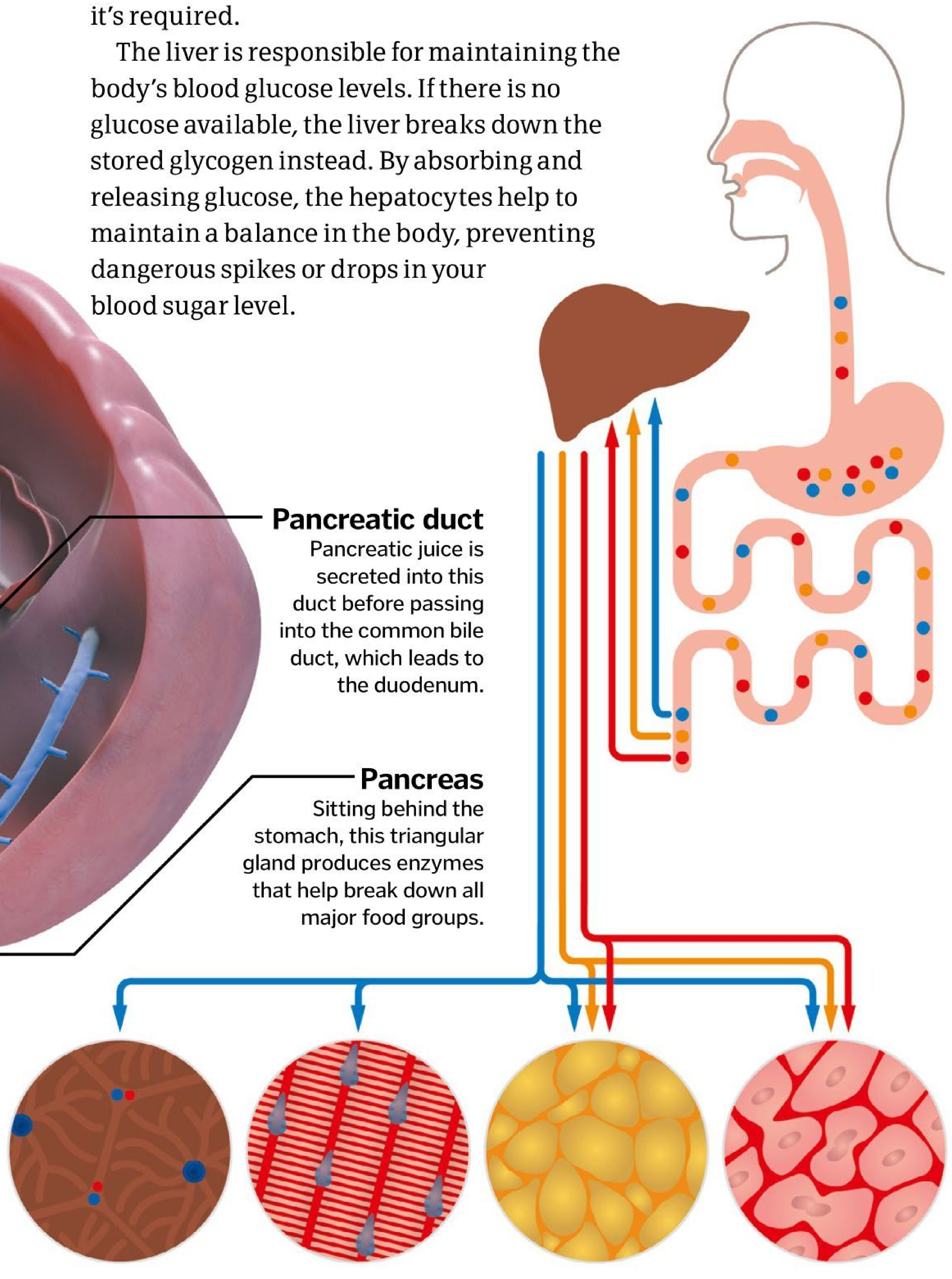
Oesophagus
Roughly 25 centimetres long, this muscular tube carries food, liquids and saliva from the throat to the stomach.

Liver
The liver performs over 500 functions, and is involved in the removal of harmful substances, protein production and energy generation, as well as digestion.

Pancreatic duct
Pancreatic juice is secreted into this duct before passing into the common bile duct, which leads to the duodenum.

Pancreas
Sitting behind the stomach, this triangular gland produces enzymes that help break down all major food groups.

Duodenum
The shortest part of the small intestine, this is where bile and pancreatic juice perform their digestive functions.



Hepatic tissue
If there is excess glucose in the body, the hormone insulin triggers the liver's hepatocyte cells to convert glucose into glycogen.

Muscle fibres
Both the liver's muscle cells and hepatic cells are able to store glycogen within them.

Adipose cells
These cells store excess fatty acids in the form of long-chain fat molecules.

Cellular growth and repair
A process called anabolism builds amino acids into proteins, which can then be used to construct cells and produce enzymes.

> *"Around a quarter of your blood supply passes through your liver every minute"*

© SolyoImages

What's inside your head

A look at how our thinking machines are put together

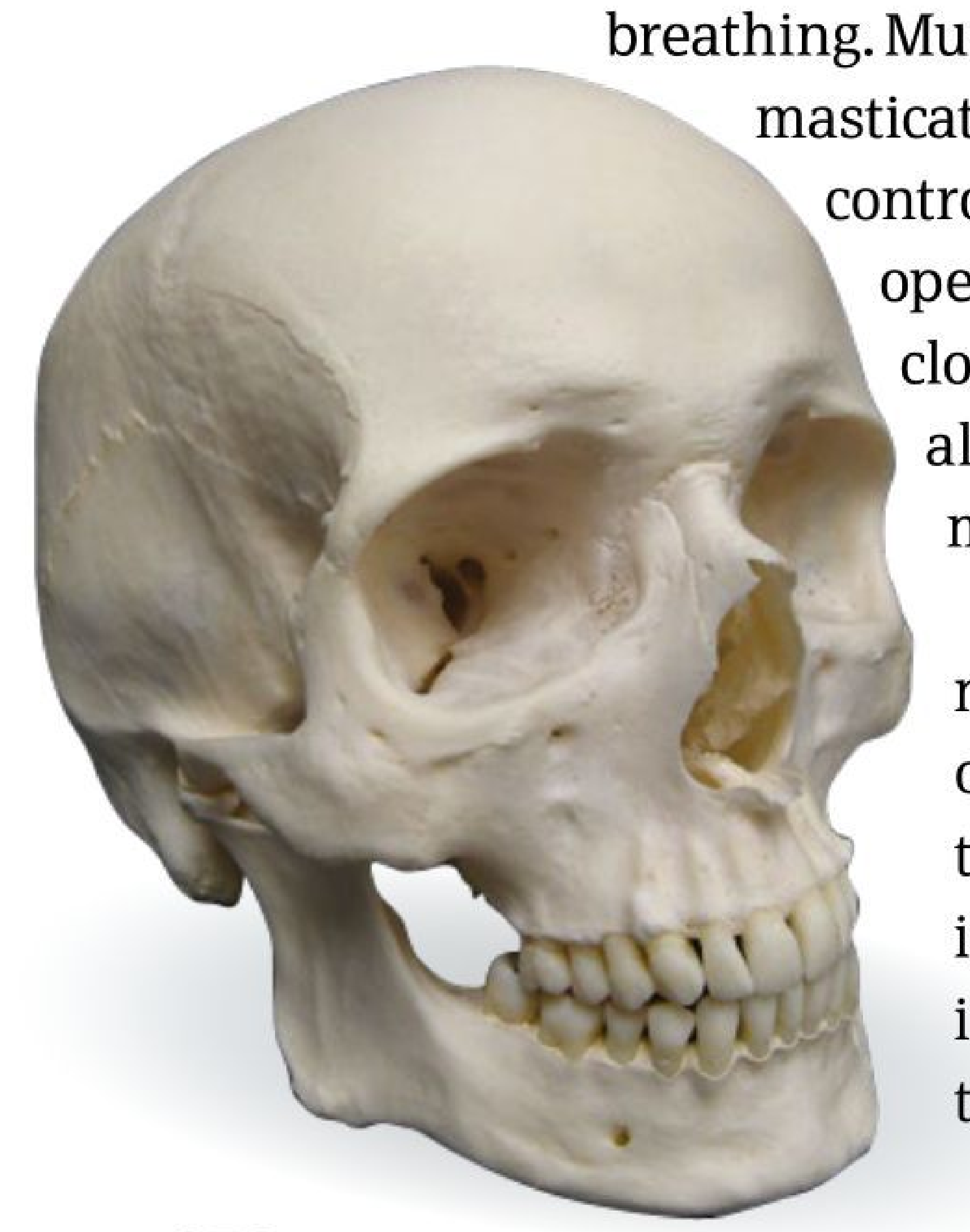
From birth, the head of a baby will grow very rapidly. By the age of two the bones will have fused together, although growth continues until the age of seven during which the shape and size of the skull are altered. An adult human head is made from 22 bones. Eight are present in the cranium, and 14 form the face. Together they make the skull, which provides a framework for all the features of our head.

The primary purpose of the skull is to prevent damage to the brain. Without it, even a small force against the head could cause serious brain damage. Before birth, the skull develops holes in which are found the various features of the head.

The skull has three main structural features. Cavities known as orbits contain the eyes, providing protection but also allowing muscles, nerves, blood supply and tissue to reach the eyes. Paranasal sinuses house the nasal cavity and also contain air-filled spaces, which are responsible for making people sound different. Finally, the head is held together by sutures, which are soft fibres at birth but later harden to give the appearance of stitches. They become immovable joints which stop the head falling apart.

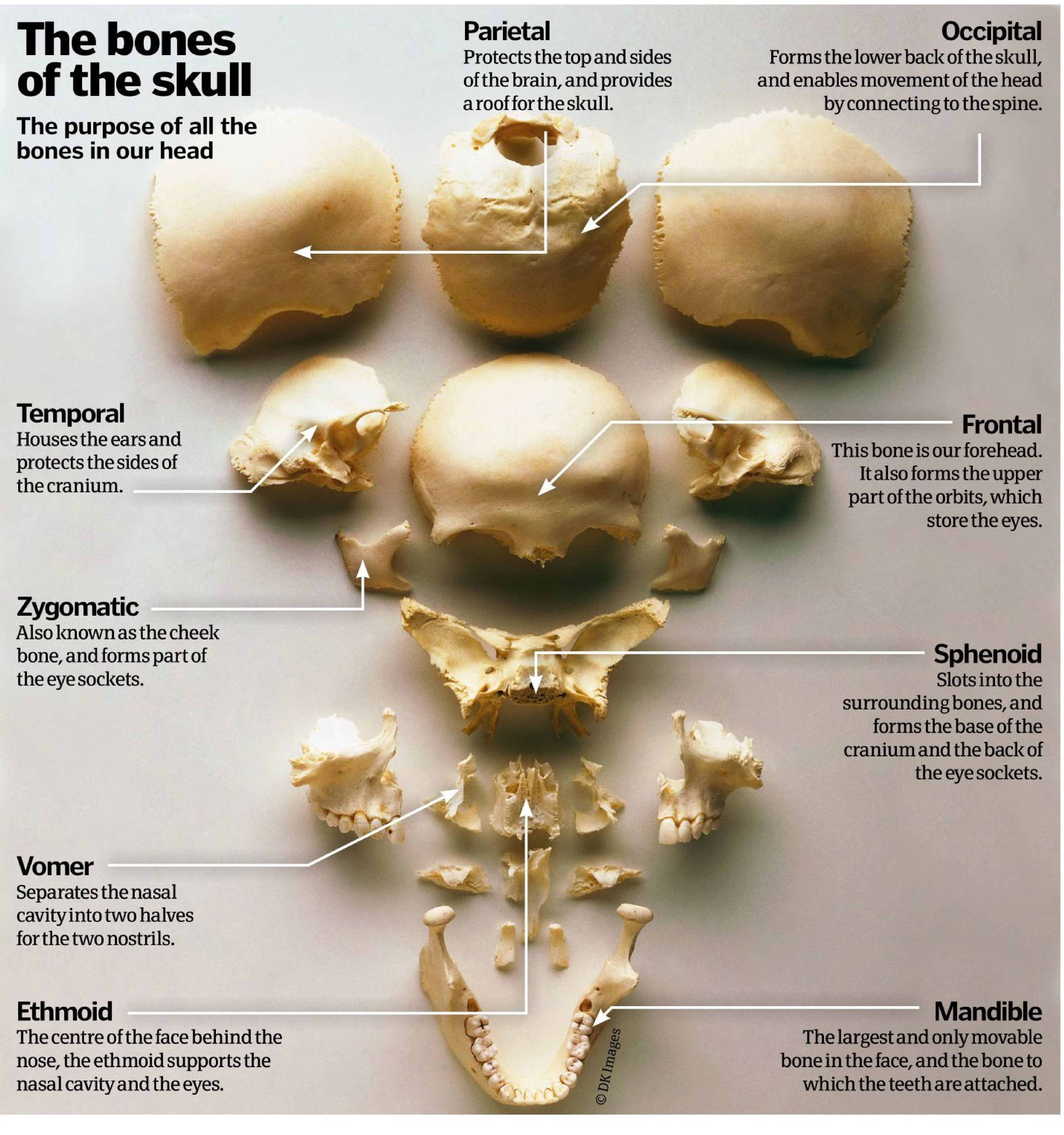
The muscles of the head are stretched over the bones in the cranium and face like sheets. There are two main categories of muscles. The muscles of facial expressions are responsible for moving the mouth, altering the chin and moving the cheeks to assist eating and breathing. Muscles of mastication directly control eating, opening and closing the jaw and allow sideways movements.

Smaller muscles control other portions of the face including the inner ear and the eye.



The bones of the skull

The purpose of all the bones in our head



Parietal
Protects the top and sides of the brain, and provides a roof for the skull.

Occipital
Forms the lower back of the skull, and enables movement of the head by connecting to the spine.

Temporal
Houses the ears and protects the sides of the cranium.

Frontal
This bone is our forehead. It also forms the upper part of the orbits, which store the eyes.

Zygomatic
Also known as the cheek bone, and forms part of the eye sockets.

Sphenoid
Slots into the surrounding bones, and forms the base of the cranium and the back of the eye sockets.

Vomer
Separates the nasal cavity into two halves for the two nostrils.

Ethmoid
The centre of the face behind the nose, the ethmoid supports the nasal cavity and the eyes.

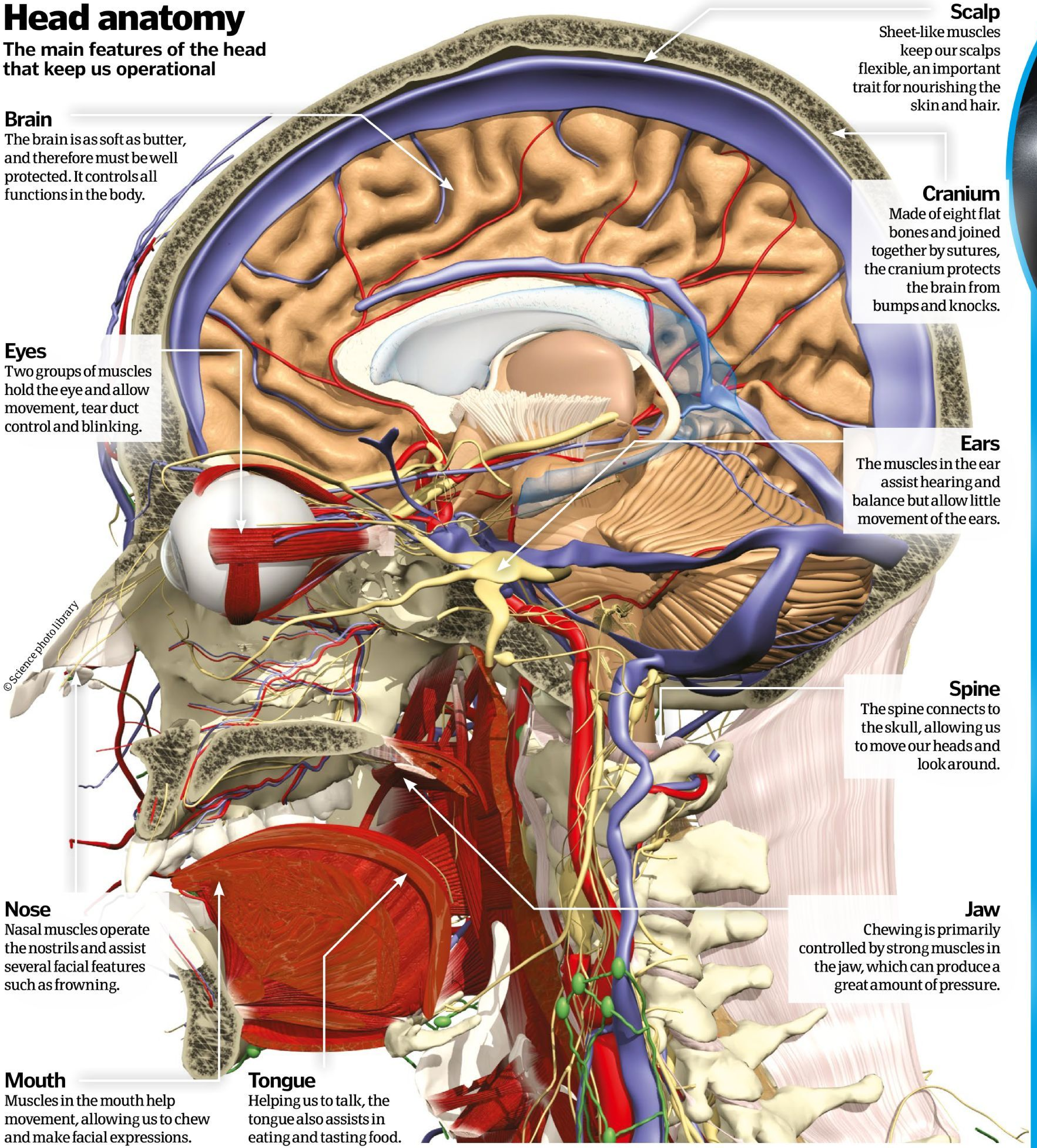
Mandible
The largest and only movable bone in the face, and the bone to which the teeth are attached.

© DK Images

DID YOU KNOW? *By measuring the skull, forensic anthropologists can determine the age, race and gender of a skeleton*

Head anatomy

The main features of the head that keep us operational



Brain
The brain is as soft as butter, and therefore must be well protected. It controls all functions in the body.

Eyes
Two groups of muscles hold the eye and allow movement, tear duct control and blinking.

Nose
Nasal muscles operate the nostrils and assist several facial features such as frowning.

Mouth
Muscles in the mouth help movement, allowing us to chew and make facial expressions.

Tongue
Helping us to talk, the tongue also assists in eating and tasting food.

Scalp
Sheet-like muscles keep our scalps flexible, an important trait for nourishing the skin and hair.

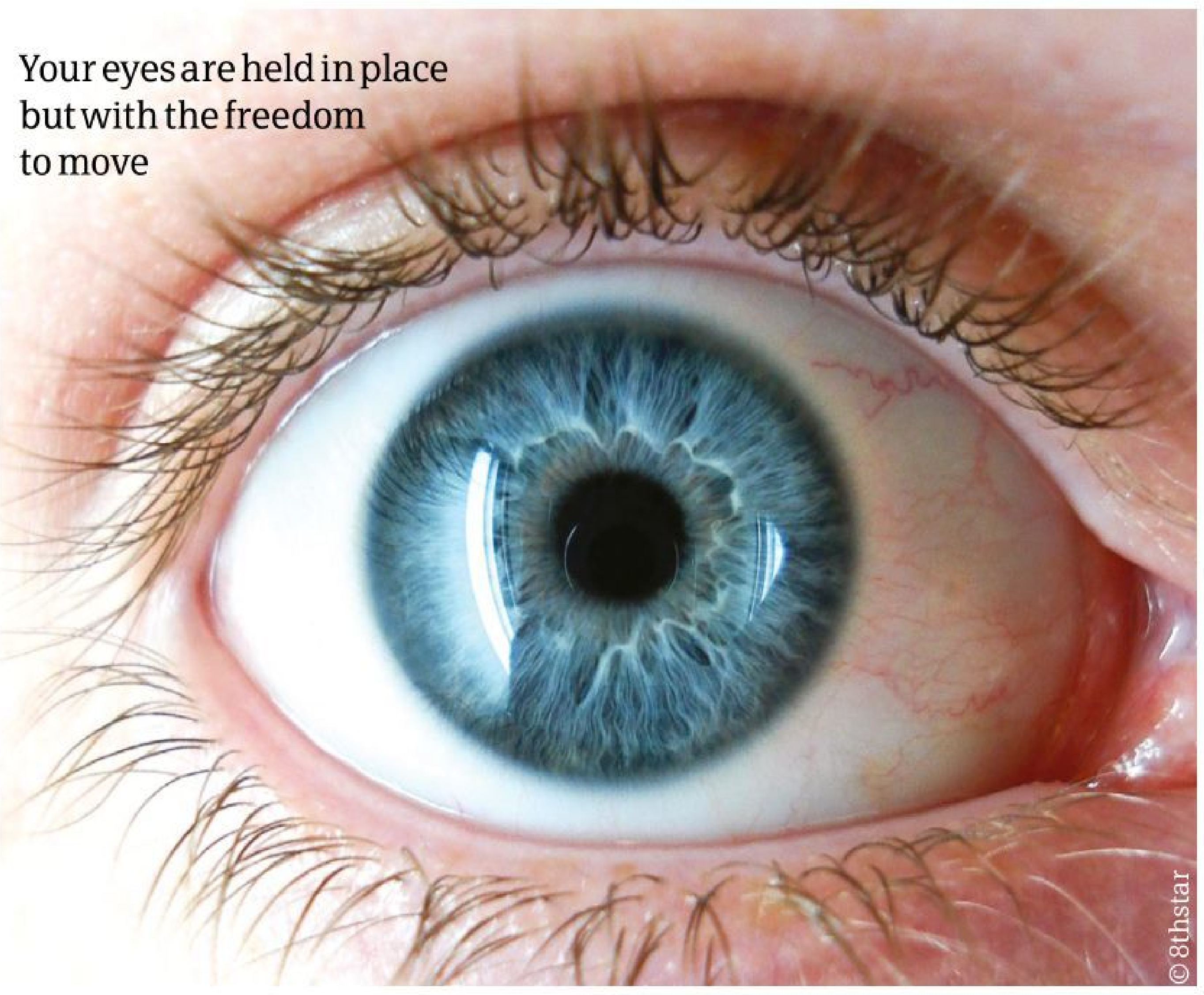
Cranium
Made of eight flat bones and joined together by sutures, the cranium protects the brain from bumps and knocks.

Ears
The muscles in the ear assist hearing and balance but allow little movement of the ears.

Spine
The spine connects to the skull, allowing us to move our heads and look around.

Jaw
Chewing is primarily controlled by strong muscles in the jaw, which can produce a great amount of pressure.

© Science photo library



Your eyes are held in place but with the freedom to move

© 8thstar

A strong jaw and teeth allow us to chew and digest food

Head injuries must always be taken very seriously

What's a knockout?

When the head is struck hard enough, a person can become unconscious. This can cause long-lasting head injuries and must be treated immediately. As the head is struck, the brain processes all the information it receives from the sensory nerves to formulate an appropriate response, be it forcing the person to withdraw, pushing their aggressor or holding the injured area. However, the brain also has a limit on how much it can process, and a hard enough blow may overload it with information.

To prevent any further damage to the head, the brain stops communicating with the body, causing unconsciousness. Although it may seem similar to sleep, an unconscious person will not respond to people or noises and will only wake up once the brain begins communicating with the body again.

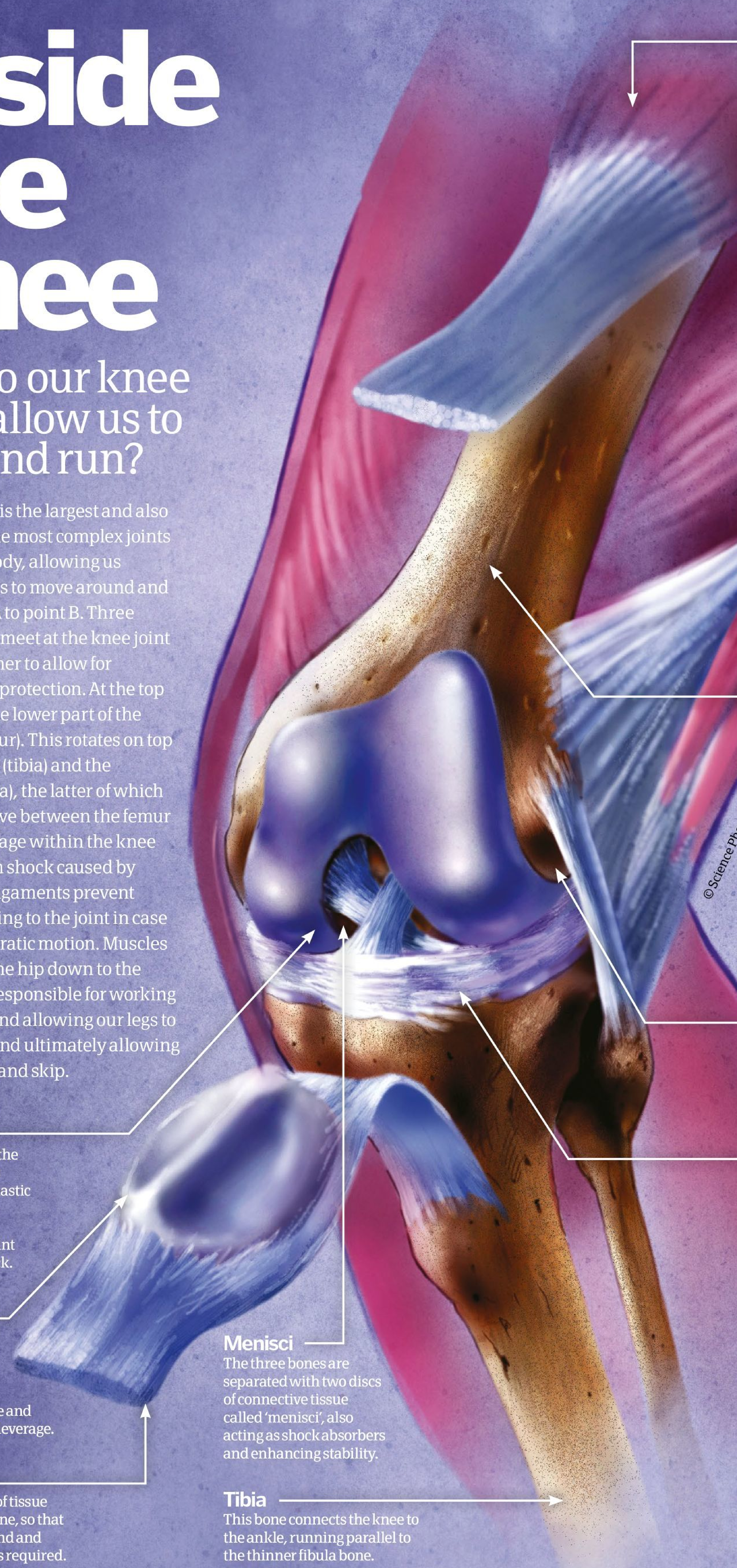
Inside the knee

How do our knee joints allow us to walk and run?

The knee is the largest and also one of the most complex joints in the body, allowing us bipedal humans to move around and get from point A to point B. Three different bones meet at the knee joint and work together to allow for movement and protection. At the top of the knee is the lower part of the thighbone (femur). This rotates on top of the shinbone (tibia) and the kneecap (patella), the latter of which moves in a groove between the femur and tibia. Cartilage within the knee cushions it from shock caused by motion, while ligaments prevent damage occurring to the joint in case of unusual or erratic motion. Muscles running from the hip down to the knee joint are responsible for working the knee joint and allowing our legs to bend, stretch, and ultimately allowing us to walk, run and skip.

The knee structure

How does everything work in tandem to allow for movement?



© Science Photo Library

Quadriceps
The quadriceps, made up of four muscles, are on the front of the thigh and help to straighten the leg.

Hamstrings
Hamstring muscles running from the thigh to the knee joint are responsible for bending the leg at the knee.

Femur
This bone runs from the hip to the knee joint. It is the thickest and the longest bone in the human body.

Synovial membrane
The soft tissue at the centre of the knee joint contains synovial fluid, providing lubrication for the moving knee.

Ligaments
These elastic bands of tissue connect the bones together and provide stability and strength to the knee joint.

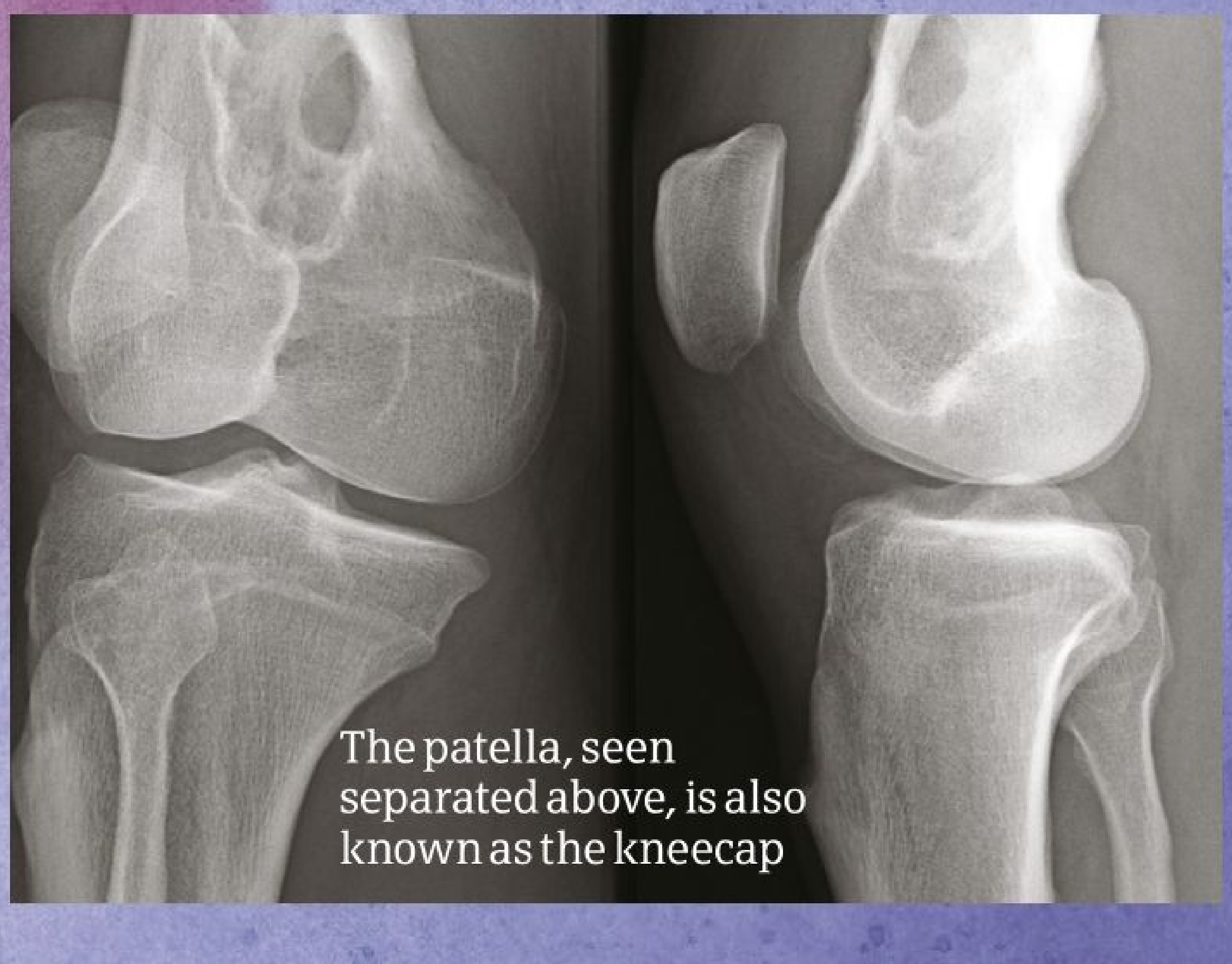
Cartilage
The point at which the three bones meet is covered in tough, elastic articular cartilage, allowing smooth movement of the joint and absorbing shock.

Patella
This bone slides at the front of the femur and tibia as the knee moves, protecting the knee and giving the muscles leverage.

Tendons
These tough cords of tissue attach muscle to bone, so that the muscles can bend and straighten the leg as required.

Menisci
The three bones are separated with two discs of connective tissue called 'menisci', also acting as shock absorbers and enhancing stability.

Tibia
This bone connects the knee to the ankle, running parallel to the thinner fibula bone.



The patella, seen separated above, is also known as the kneecap

What is thermoregulation?

Why do humans need to maintain a constant internal body temperature of 37°C?

Your cells work best when the temperature inside your body is 37 degrees Celsius (98.6 degrees Fahrenheit). Thermoregulation is a homeostatic function that enables you to maintain this core temperature independent of how hot or cold your surroundings are.

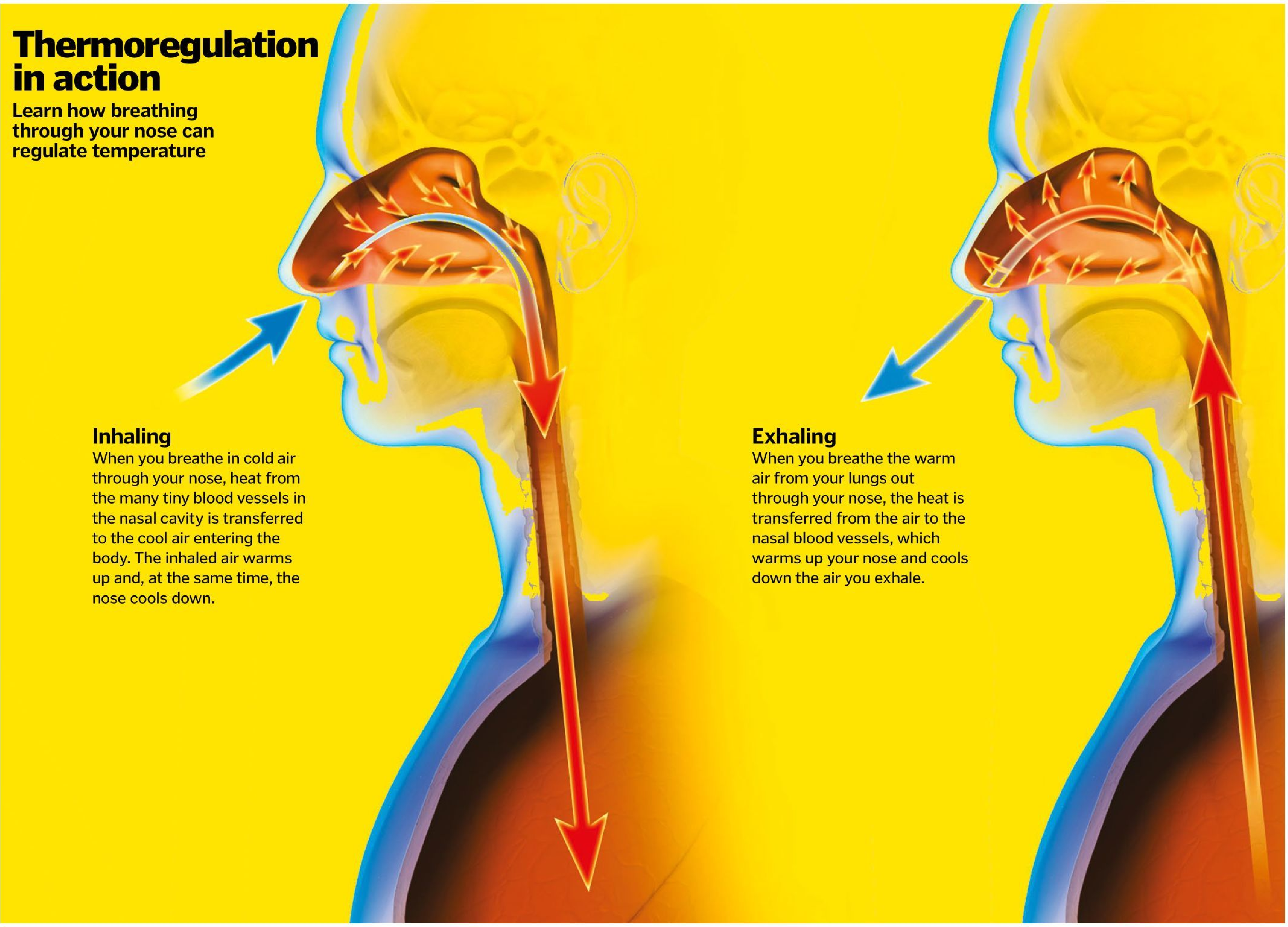
Humans are able to regulate body temperature via a combination of internal processes and external actions. The latter includes behavioural responses, such as heading for shade when we're exposed to too much Sun.

If that doesn't help, the body also has a number of automatic responses that help regulate temperature. The main organ involved is the skin, which is controlled by the autonomic nervous system. When your surroundings heat up, the brain triggers a series of chemicals which tell your blood vessels to dilate (widen). This not only brings warm blood to the surface of the skin where it can more easily radiate heat away, but it also releases sweat through the pores. The body emits heat to vaporise the moisture from the skin, cooling us in the process.

Conversely, when your surroundings grow cold, your blood vessels constrict (narrow), reducing the flow of blood to the surface. The hairs on your skin stand on end and you may shiver and get goosebumps as the skin's arrector pili muscles contract, pulling the hairs erect to trap air near the skin's surface.

Thermoregulation in action

Learn how breathing through your nose can regulate temperature



Inhaling

When you breathe in cold air through your nose, heat from the many tiny blood vessels in the nasal cavity is transferred to the cool air entering the body. The inhaled air warms up and, at the same time, the nose cools down.

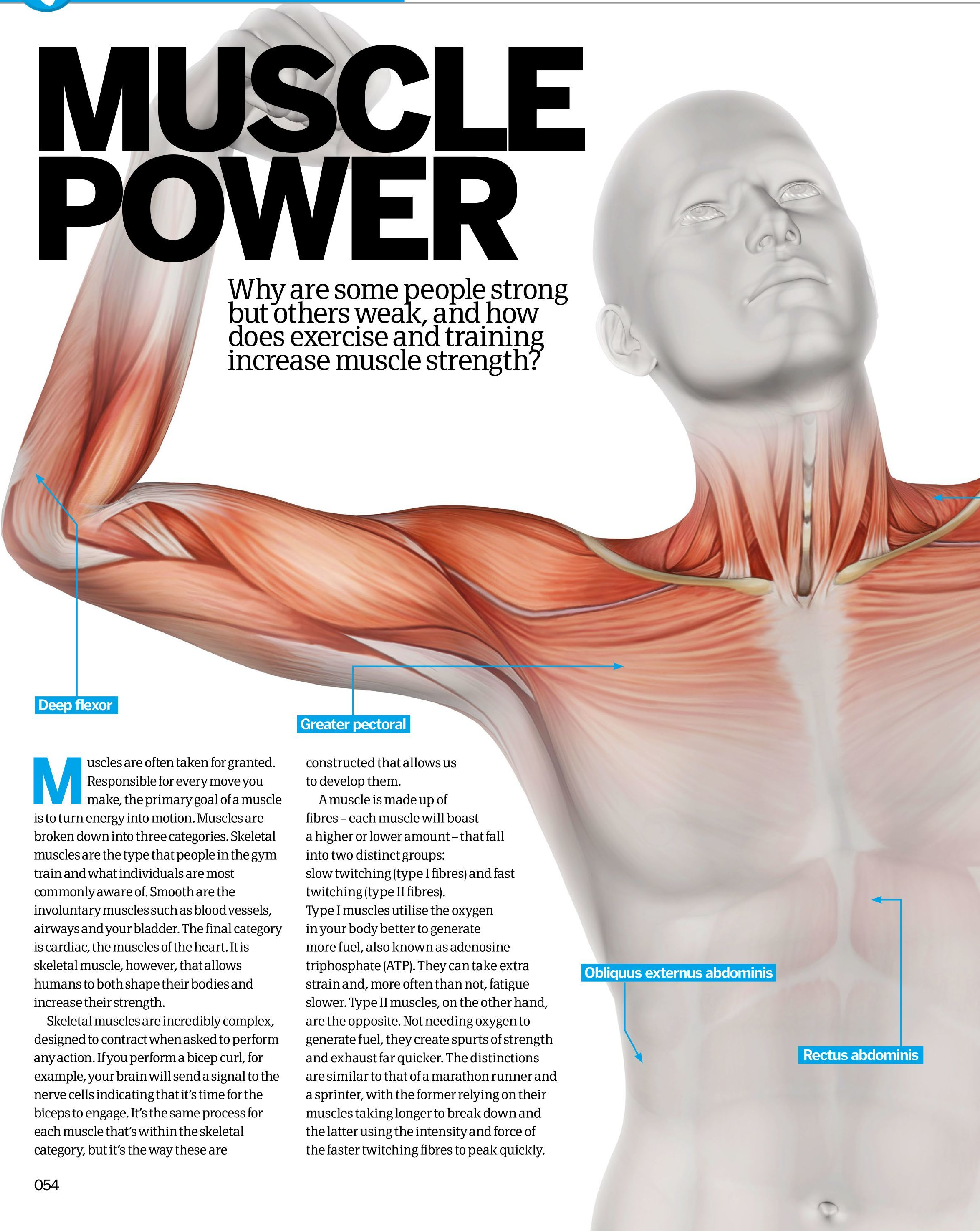
Exhaling

When you breathe the warm air from your lungs out through your nose, the heat is transferred from the air to the nasal blood vessels, which warms up your nose and cools down the air you exhale.

© SPL; Thinkstock

MUSCLE POWER

Why are some people strong but others weak, and how does exercise and training increase muscle strength?



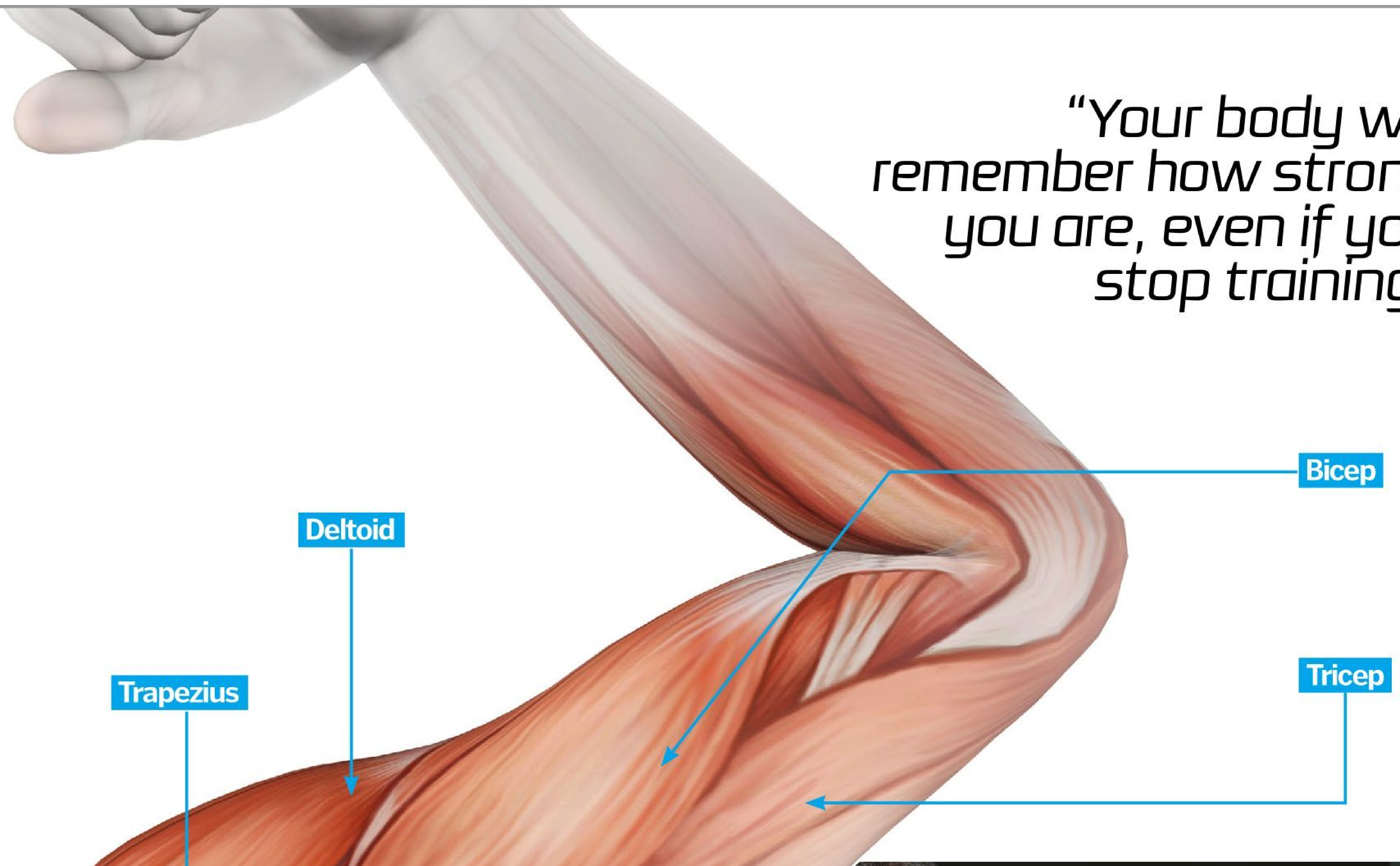
Muscles are often taken for granted. Responsible for every move you make, the primary goal of a muscle is to turn energy into motion. Muscles are broken down into three categories. Skeletal muscles are the type that people in the gym train and what individuals are most commonly aware of. Smooth are the involuntary muscles such as blood vessels, airways and your bladder. The final category is cardiac, the muscles of the heart. It is skeletal muscle, however, that allows humans to both shape their bodies and increase their strength.

Skeletal muscles are incredibly complex, designed to contract when asked to perform any action. If you perform a bicep curl, for example, your brain will send a signal to the nerve cells indicating that it's time for the biceps to engage. It's the same process for each muscle that's within the skeletal category, but it's the way these are constructed that allows us to develop them.

A muscle is made up of fibres – each muscle will boast a higher or lower amount – that fall into two distinct groups: slow twitching (type I fibres) and fast twitching (type II fibres). Type I muscles utilise the oxygen in your body better to generate more fuel, also known as adenosine triphosphate (ATP). They can take extra strain and, more often than not, fatigue slower. Type II muscles, on the other hand, are the opposite. Not needing oxygen to generate fuel, they create spurts of strength and exhaust far quicker. The distinctions are similar to that of a marathon runner and a sprinter, with the former relying on their muscles taking longer to break down and the latter using the intensity and force of the faster twitching fibres to peak quickly.

DID YOU KNOW? *The gluteus maximus – that's your bottom – is the largest muscle in the human body*

> "Your body will remember how strong you are, even if you stop training"



Lifting a weight tears muscle fibres apart

It's these processes that allow us to both manipulate a muscle and make it stronger. Every time you lift a weight you're tearing these muscle fibres apart, forcing the body to repair them. Once healed, the fibres are thicker than before, a process that can be manipulated with the right diet. Bodybuilders get protein into their system as soon as possible after a workout, as the substance is broken down into amino acids that are used to produce and repair muscles. Your diet can even influence how effective this is: fast-acting carbohydrates play an important role in spiking insulin levels, which in turn replace muscle glycogen (reserve source of glucose) used during training. Such a process will also filter protein where it's needed, for maximum recovery and growth. This is why muscles get bigger and stronger with rest, and not at the gym where you're in fact breaking and destroying them.

These principles shift across in terms of how muscles get stronger, too. The notion that lifting heavy weights at a lower rep range will increase body mass, whereas doing the opposite will make the muscle more visible, is a myth. Instead, when you train with heavy weights and force your muscles to expend all their ATP, you put the body in a state to recruit more muscle fibres and stimulate those that are missed when focusing on lighter weights. You're essentially teaching your muscles that they can become stronger. It won't suddenly make them bigger, but it will activate more fibres that in turn help you lift more. This type of training produces a form of muscle hypertrophy, which, in this instance, is increasing the size of your muscle cells. Hypertrophy can be manipulated to both boost muscular strength or simply focus on increasing body mass.

Your body will also remember how strong you are, even if you stop training. Although you'd have to work back up to your previous level, it would take half the time thanks to muscle memory. Following the same approach as how we remember to perform everyday tasks, your muscles get used to the same movement and adapt accordingly.

The bigger they are…

Just because you look like The Hulk doesn't mean you're going to have the comic book character's strength. If you lift heavy weights for a low number of repetitions, you're training the muscle to take a more intense load due to the formation of new fibres. That doesn't mean you'll have the size to back it up, however, as mass corresponds to the number of calories consumed. The more food that's eaten, the quicker and more efficiently the muscle will be repaired. This is why plenty of power lifters who can pick up an incredible amount don't look like bodybuilders. Not only do they concentrate on pure strength, they also consume a massive number of calories. A bodybuilder, meanwhile, will sculpt his diet to shape and increase muscle size.

Not as strong as you might think…

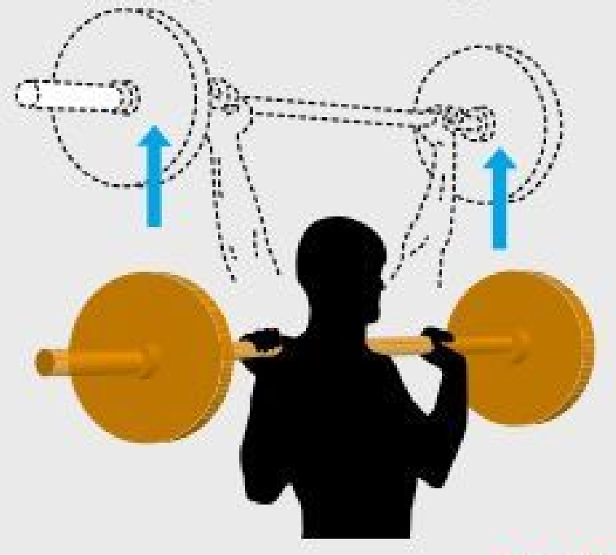
© JayJay

Shoulders

Exercise name: Military press

How to do it: Using weights, bend your legs, lift up the bar in line with your shoulders and push from your deltoids until your arms are straight. Repeat.

Details: With the correct weight and intensity, it'll tear many muscles apart and increase your strength.



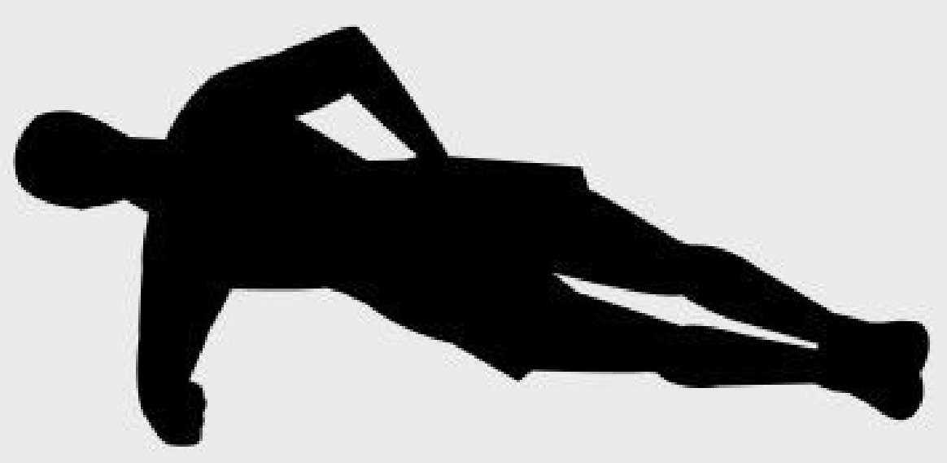
STRENGTH RATING: ●●●●○

Mid-section

Exercise name: Side plank

How to do it: Lay on your side and hoist your body up using the leg and arm you're resting on. Hold this position for as long as you can.

Details: The side plank will trigger both abdominals and mid-section, for a more efficient centre of gravity.



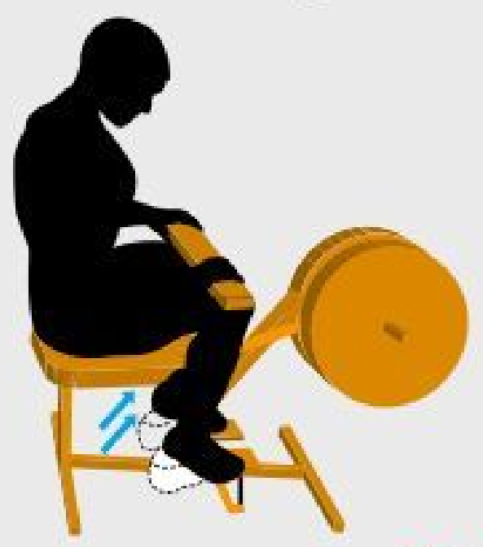
STRENGTH RATING: ●●○○○

Calves

Exercise name: Calf raise

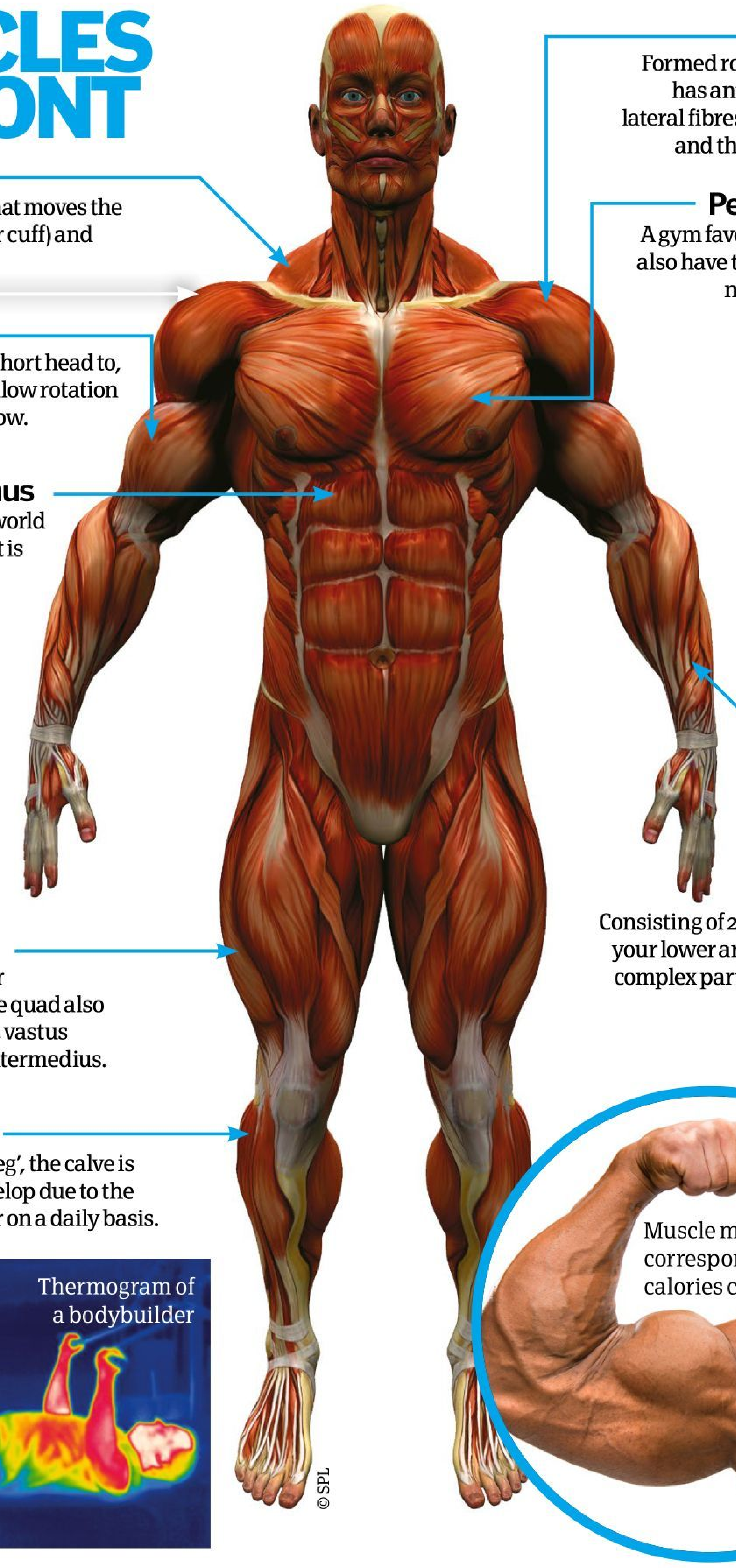
How to do it: Using a Smith machine, stand under the barbell and place it on your trapezius muscles. Push from calves and stand on your tiptoes.

Details: Extremely difficult to enhance, the calf raise when done with a barbell will target this muscle.



STRENGTH RATING: ●●○○○

MUSCLES IN FRONT



© SPL

Trapezius

A superficial muscle that moves the scapulae (in the rotator cuff) and supports the arm.

Biceps brachii

Consists of a long and short head to, among other things, allow rotation of the forearm and elbow.

Rectus abdominus

Known to the greater world as 'abs' or a 'six-pack', it is possible to possess an eight-pack, or even ten-pack.

Vastus lateralis

The largest part of your quadriceps muscle, the quad also has the rectus femoris, vastus medialis and vastus intermedius.

Gastrocnemius

Meaning 'stomach of leg', the calve is incredibly hard to develop due to the pressure it is put under on a daily basis.

Deltoid

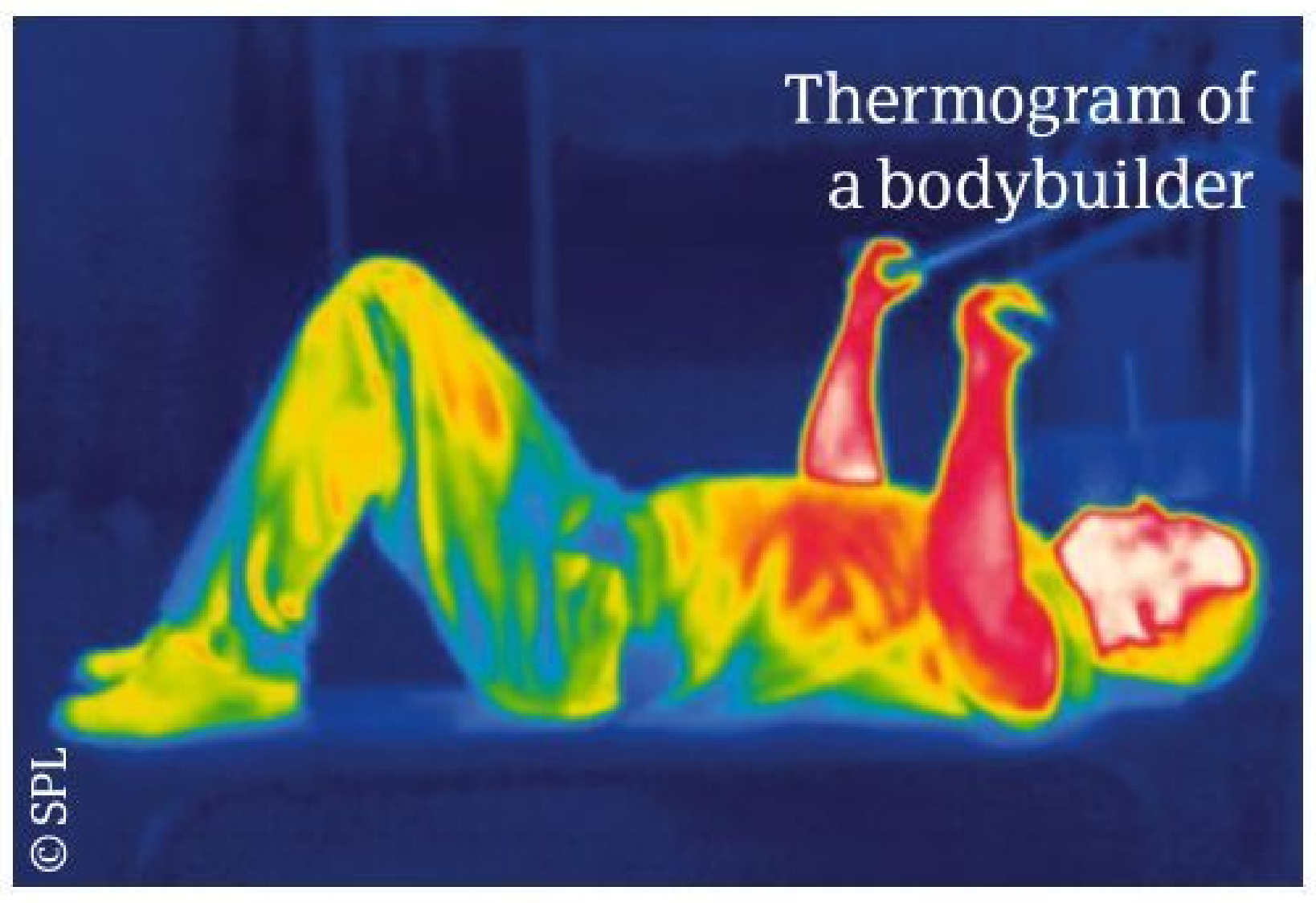
Formed round the shoulder, it has anterior, posterior and lateral fibres to support rotation and the pectorals and lats.

Pectoralis major

A gym favourite, the pectorals also have the pectoralis minor near the upper chest.

Forearm

Consisting of 20 different muscles, your lower arm is one of the most complex parts of the entire body.



Thermogram of a bodybuilder

© SPL

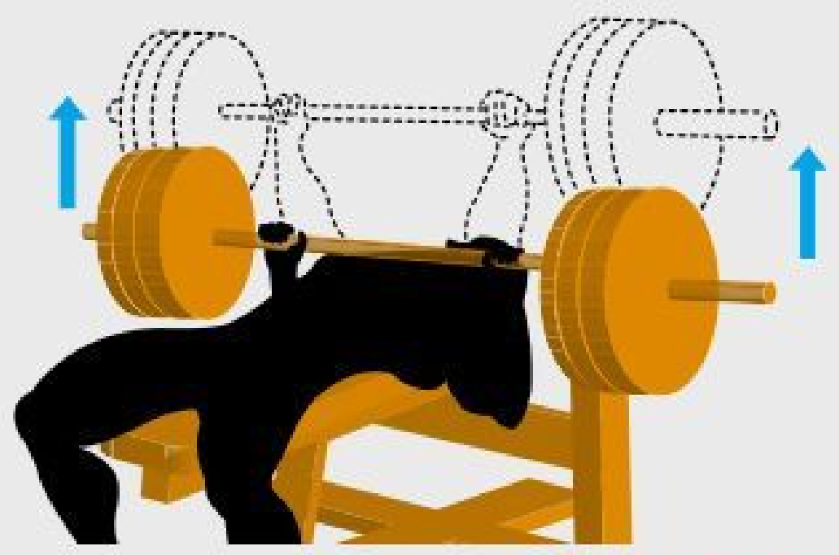
Muscle mass corresponds to calories consumed

Chest

Exercise name: Bench press

How to do it: Lie on a bench and grab a barbell, hands about shoulder width. Bring the bar to chest level and lower until arms are at 90°. Push upwards.

Details: The bench press isn't merely beneficial for your chest; it also works your shoulders and triceps.



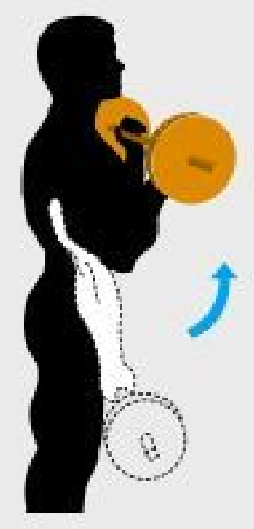
STRENGTH RATING: ●●●●○

Biceps

Exercise name: Bicep curl

How to do it: Raise a dumbbell from your side up to your shoulder rotating the arm so the palm with the weight faces up. Then lower and repeat.

Details: The biceps' relatively small size compared to other muscle groups means they're quite easy to target.



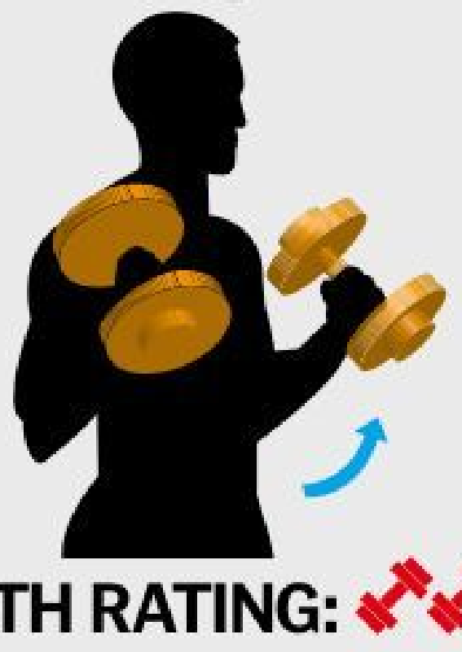
STRENGTH RATING: ●●○○○

Forearms

Exercise name: Hammer curls

How to do it: Hold a dumbbell in each hand with palms facing your body. Curl the weight up to your chest, keeping elbows locked. Lower down.

Details: Performed with a heavy weight, you can improve your grip and increase arm strength.



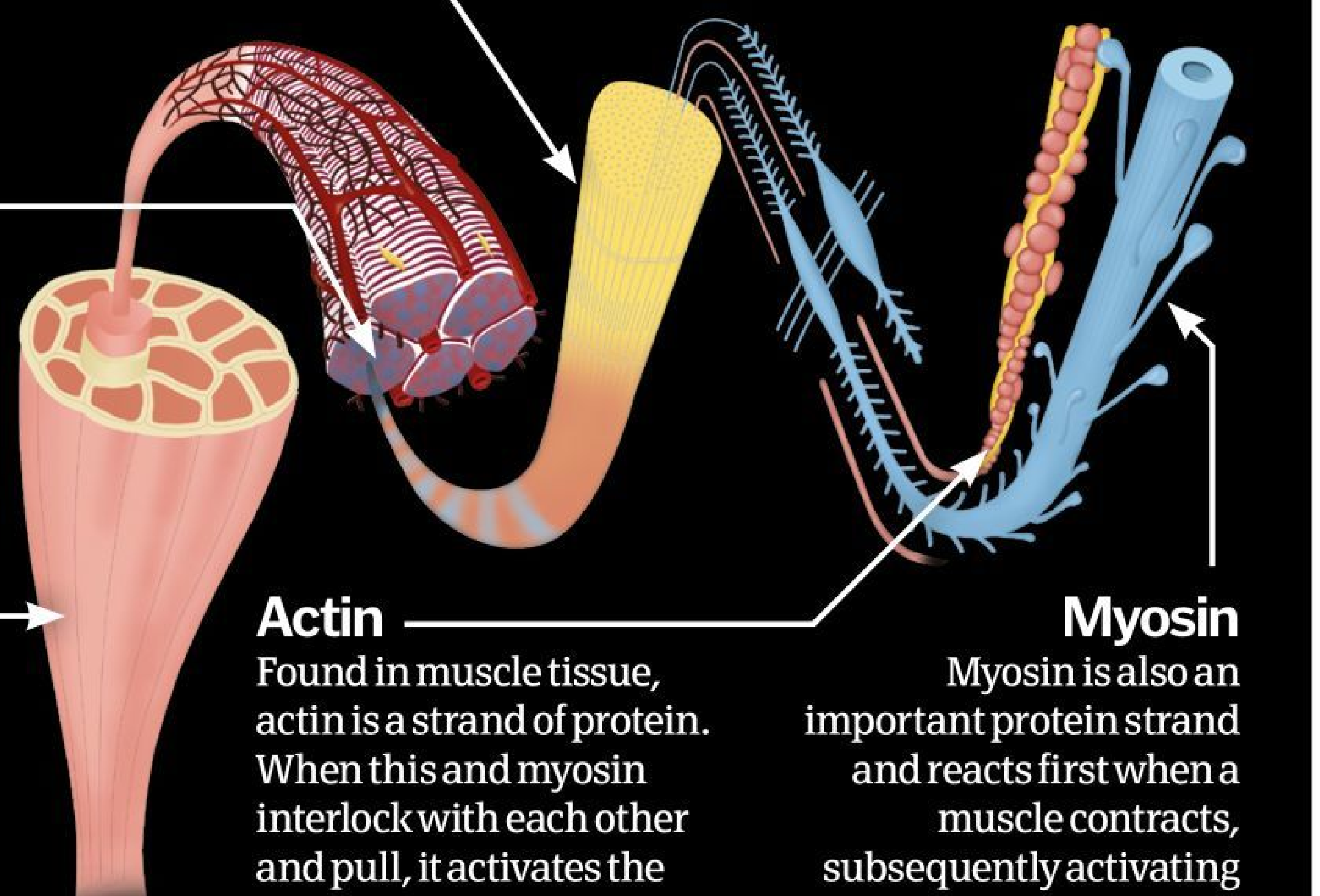
STRENGTH RATING: ●●●○○

Inside your muscle

A muscle contracts when a fibre is kicked into gear as tension is put upon it. Myofibrils, which are found within a fibre, are made up of actin and myosin. When these two threads join the myofibril shortens, or contracts. If you straighten your arm, keeping your palm facing up, and measure the length of your bicep muscle, you'll find it will become a lot smaller if you curl your hand towards the shoulder.

There are multiple types of contractions, though. Isometric contractions occur when the angle of the joint or length of muscle do not change, for example holding a dumbbell at arm's length and fighting the resistance. Such exercises are usually adapted to try and increase strength.

Isotonic contractions are the opposite and also more common, such as traditional weightlifting where, as mentioned, the muscle shortens with contraction. Although this can also be used for strength training, it's beneficial for expanding muscle size.



Myofibril

Housing the two filaments actin and myosin, this is what's found inside a muscle fibre. When the myofibril shortens, a muscle contracts.

Muscle fibres

This is a skeletal muscle cell and will fall into the mentioned 'type' categories. There can be far more than just types I and II.

Fascicle

A bundle of muscle fibres is known as a fascicle. Surrounded by perimysium – the connective tissues that groups individual fibres together – this collection makes up a muscle.

Actin

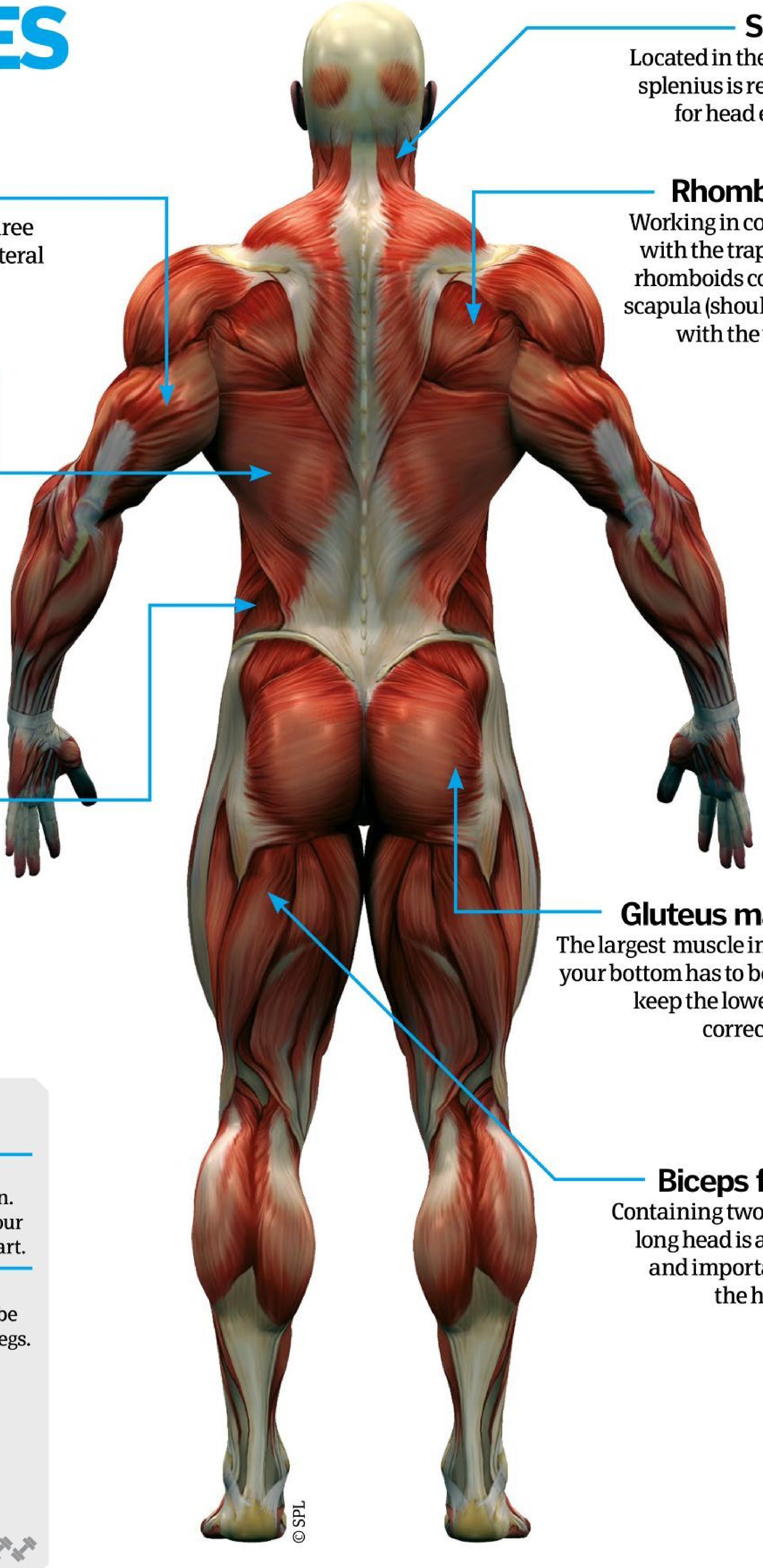
Found in muscle tissue, actin is a strand of protein. When this and myosin interlock with each other and pull, it activates the shortening of the myofibril.

Myosin

Myosin is also an important protein strand and reacts first when a muscle contracts, subsequently activating the actin thread.

DID YOU KNOW? *Many people with muscular physiques have 'unhealthy' BMIs, as muscle weighs more than fat.*

MUSCLES BEHIND


© SPL

Triceps
As the name suggests there's three parts to the muscle: the long, lateral and medial head.

Latissimus dorsi
Meaning 'broadest of the back', the lats, as they're commonly called, are an essential muscle for strengthening the entire body.

External oblique
The largest and outermost of the three muscles of the lateral anterior abdomen.

Splenius
Located in the neck, the splenius is responsible for head extension.

Rhomboideus
Working in conjunction with the trapezius, the rhomboids connect the scapula (shoulder blade) with the vertebrae.

Gluteus maximus
The largest muscle in the body, your bottom has to be strong to keep the lower part in a correct position.

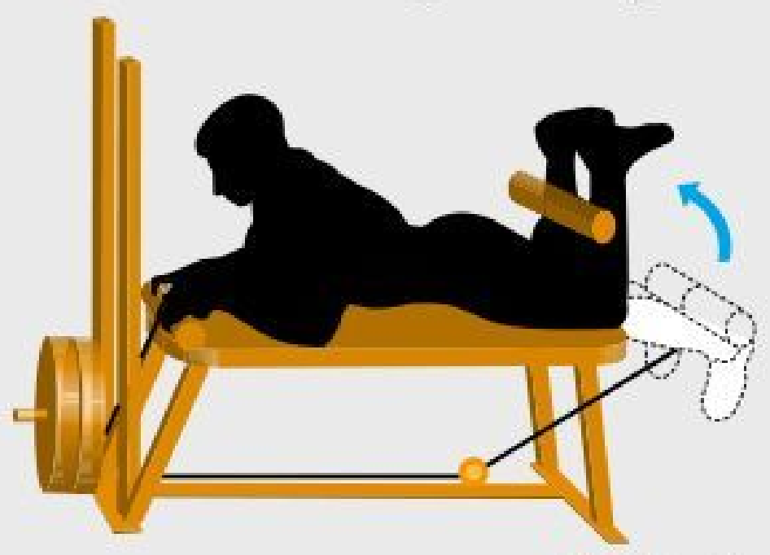
Biceps femoris
Containing two parts, the long head is an integral and important part of the hamstring.

Hamstrings

Exercise name: Hamstring curls

How to do it: Use a hamstring curl machine and lock legs into position. Push against the foam pad until your legs are at 90° and go back to the start.

Details: Curls will provide extra support to squats, meaning you'll be able to lift more weight from your legs.



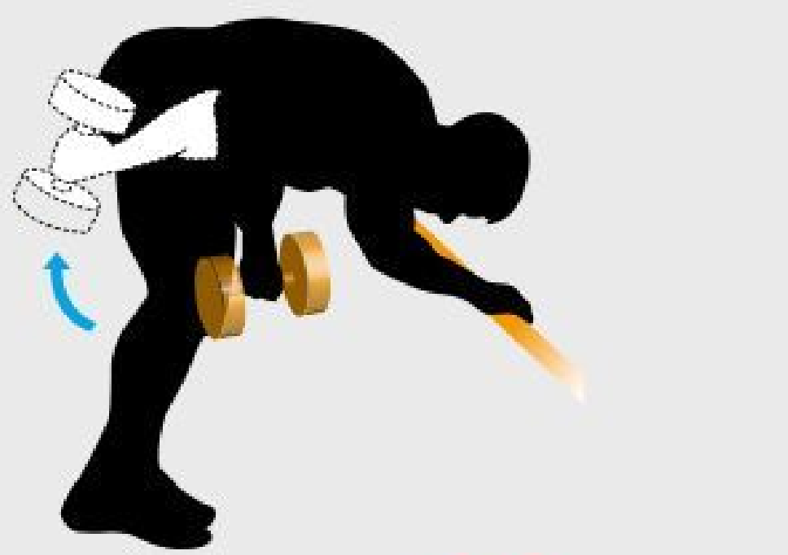
STRENGTH RATING: ●○○○○

Upper arms

Exercise name: Tricep kickback

How to do it: Take one dumbell and hold it by your side. With the elbow locked pointing to the ceiling, extend your arm behind you till it's straight.

Details: Tricep extensions hit the three different heads that make up a large part of the upper arm at once.



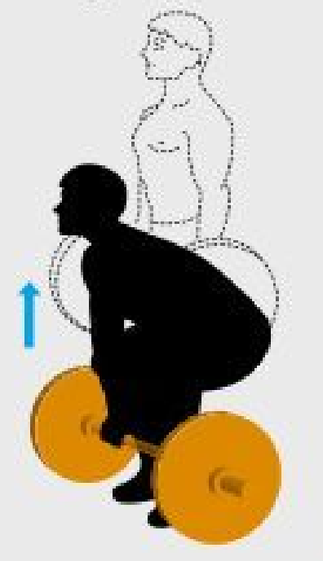
STRENGTH RATING: ●●○○○

Back

Exercise name: Deadlift

How to do it: Lay barbell on the floor. Put shins to the bar, bend knees and push from the legs. When bar passes hips, straighten back and stand up.

Details: The deadlift utilises every muscle in your body, from your back to your hamstrings.



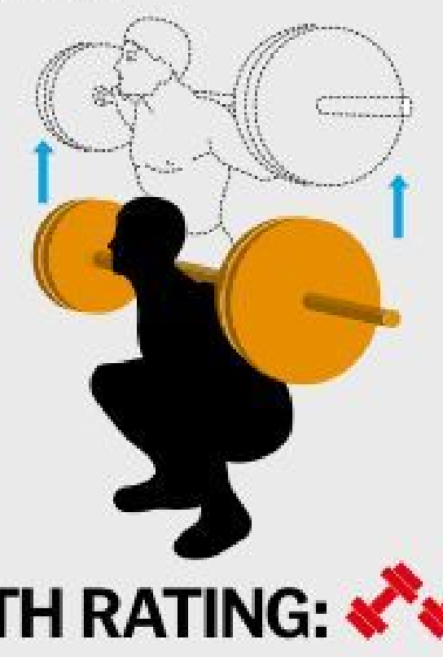
STRENGTH RATING: ●●●●●

Quadriceps

Exercise name: Squats

How to do it: Using barbell in a squat rack, place bar on trapezius. Back straight, bend knees until hamstrings parallel with floor. Push from legs.

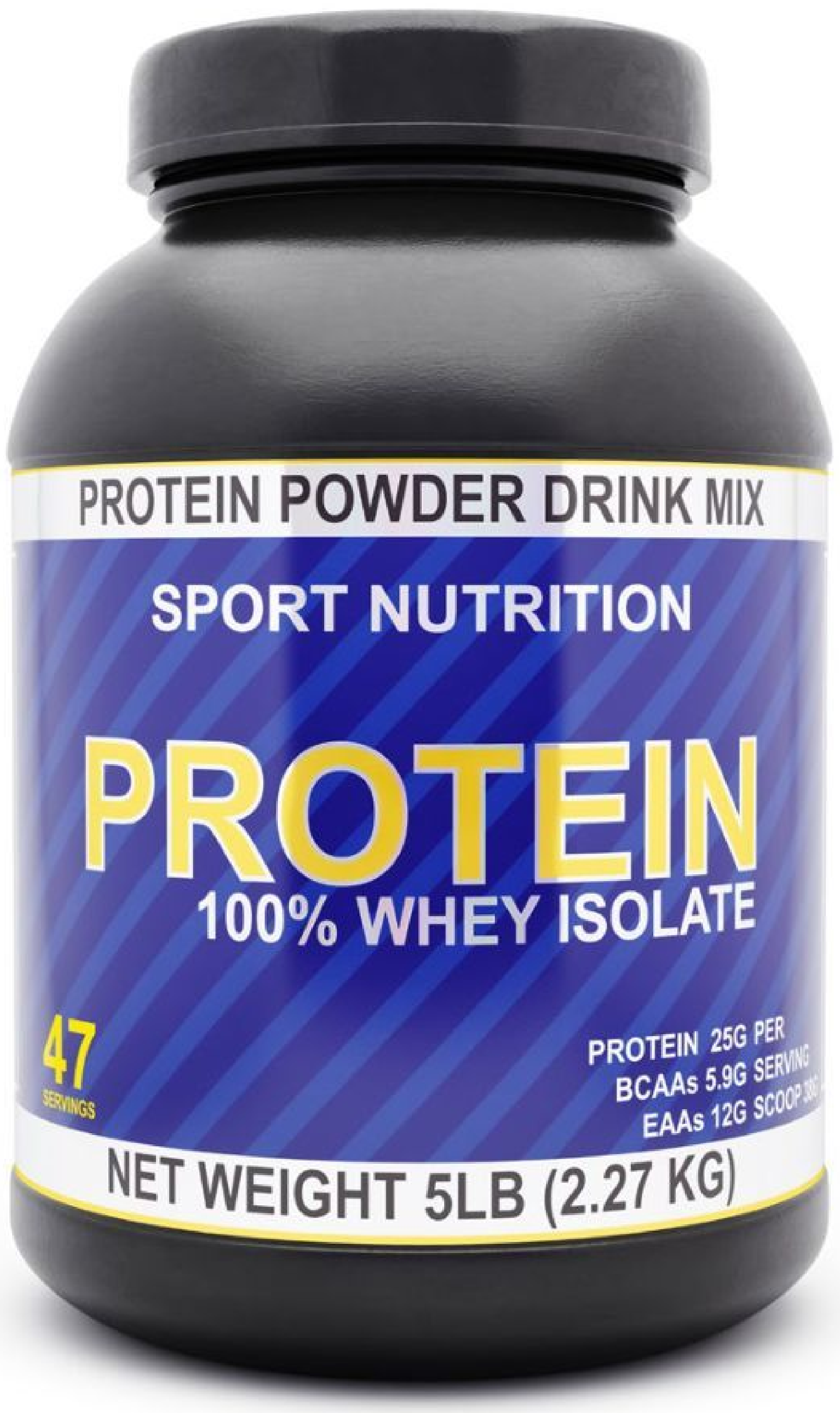
Details: Squats target all of your leg muscles, as well as most of your upper ones too.



STRENGTH RATING: ●●●●●

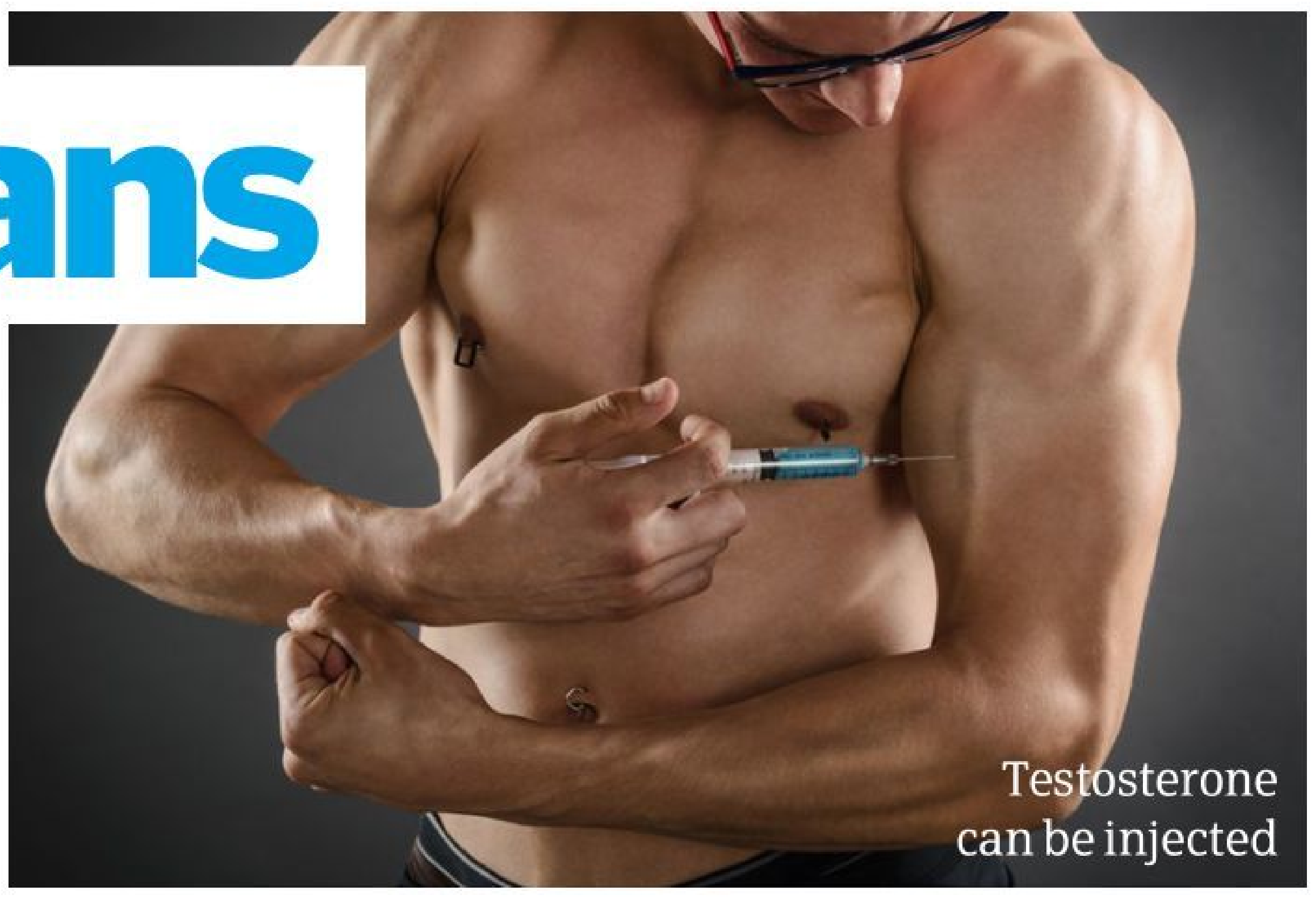
Hysterical strength – fact or fiction?

Believe it or not, on occasion a desperate mother has found the strength to lift a car to save her threatened child. Seems impossible, right? Although there's no scientific evidence to support it, the most common theory is that the rush of adrenaline from the situation increases muscle twitching, enabling the recipient to be stronger and work harder for a very short period of time. When such an event occurs, though, what you don't hear about is the damage and injuries that these heroes usually suffer. It's why the body produces lactic acid in most cases, in order to stop the body from overdoing it.



Wheys and means

Many bodybuilders will supplement their diet with nutritional products – or even illegal drugs – to enhance their physique. Discover these common methods of bulking up…


Testosterone can be injected

WHEY PROTEIN

A must for anyone trying to increase size/strength, getting enough protein is crucial. Not only is it the building block for muscles – amino acids construct protein which then builds muscle – but eating enough (usually around 1.5-2.0g per lb of bodyweight) will see the body start to grow.

CREATINE

A natural substance already found in the body, creatine is an amino acid compound that stores energy. Supplementing with creatine can stop ATP levels (the substance that starts to drain when muscles are contracted) from depleting as quickly, meaning you can lift more weight for longer.

ANABOLIC STEROIDS

Ranging from injectables – such as pure testosterone which enables the body to grow beyond its means – and orals, steroids enter the muscle cells and stimulate them, which increases their production. Due to this, more cells will be developed, making the body bigger.

SCIENCE OF VISION

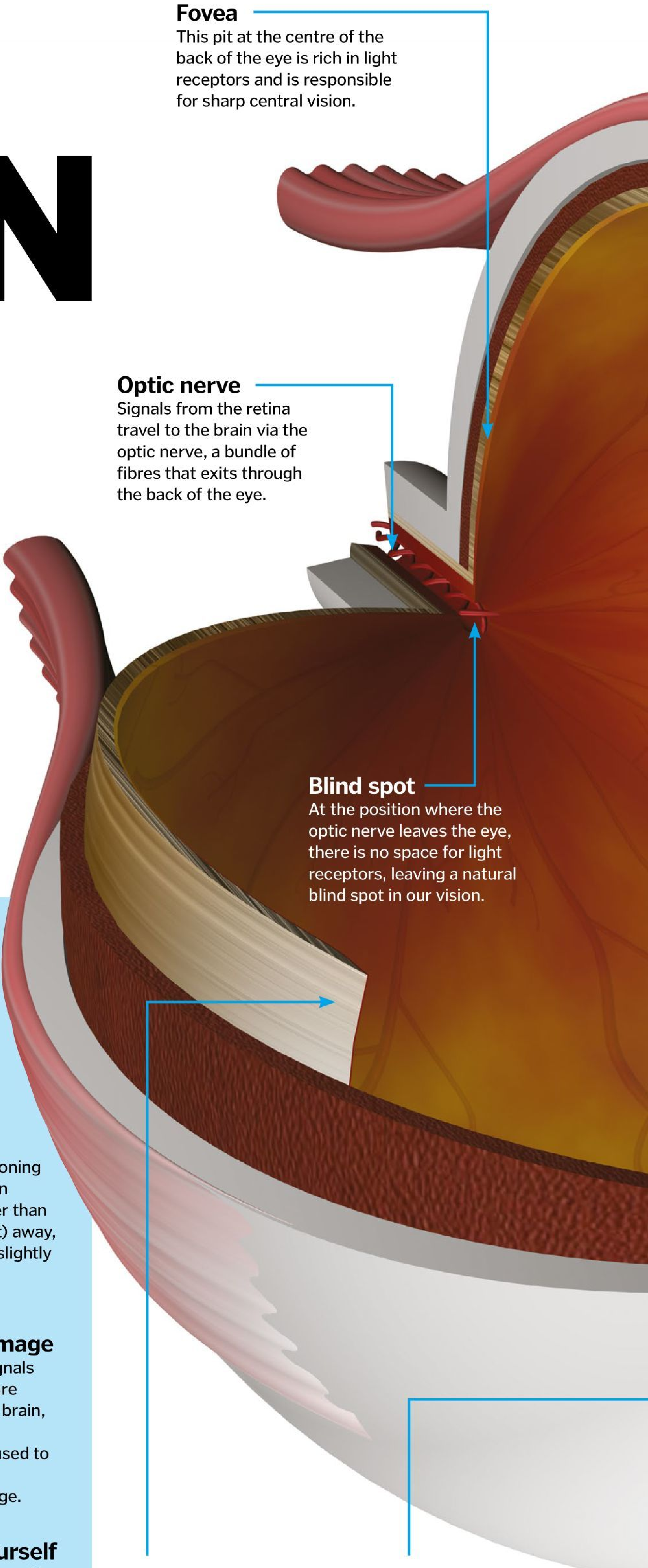
Uncovering one of the most complex constructs in the natural world

The structure of the human eye is so complex that it's difficult to believe that it's not the product of intelligent design but by looking at the eyes of other animals, scientists have shown that it evolved very gradually from a simple light-dark sensor over the course of around 100 million years.

The eye functions in a very similar way to a camera, with an opening through which the light enters, a lens for focusing and a light-sensitive membrane at the back.

The amount of light that enters the eye is controlled by the circular and radial muscles in the iris, which contract and relax to alter the size of the pupil. The light first passes through a tough protective sheet called the cornea, and then moves into the lens. This adjustable structure bends the light, focusing it down to a point on the retina, at the back of the eye.

The retina is covered in millions of light-sensitive receptors known as rods and cones. Each receptor contains pigment molecules, which change shape when they are hit by light, triggering an electrical message that travels to the brain via the optic nerve.



Fovea
This pit at the centre of the back of the eye is rich in light receptors and is responsible for sharp central vision.

Optic nerve
Signals from the retina travel to the brain via the optic nerve, a bundle of fibres that exits through the back of the eye.

Blind spot
At the position where the optic nerve leaves the eye, there is no space for light receptors, leaving a natural blind spot in our vision.

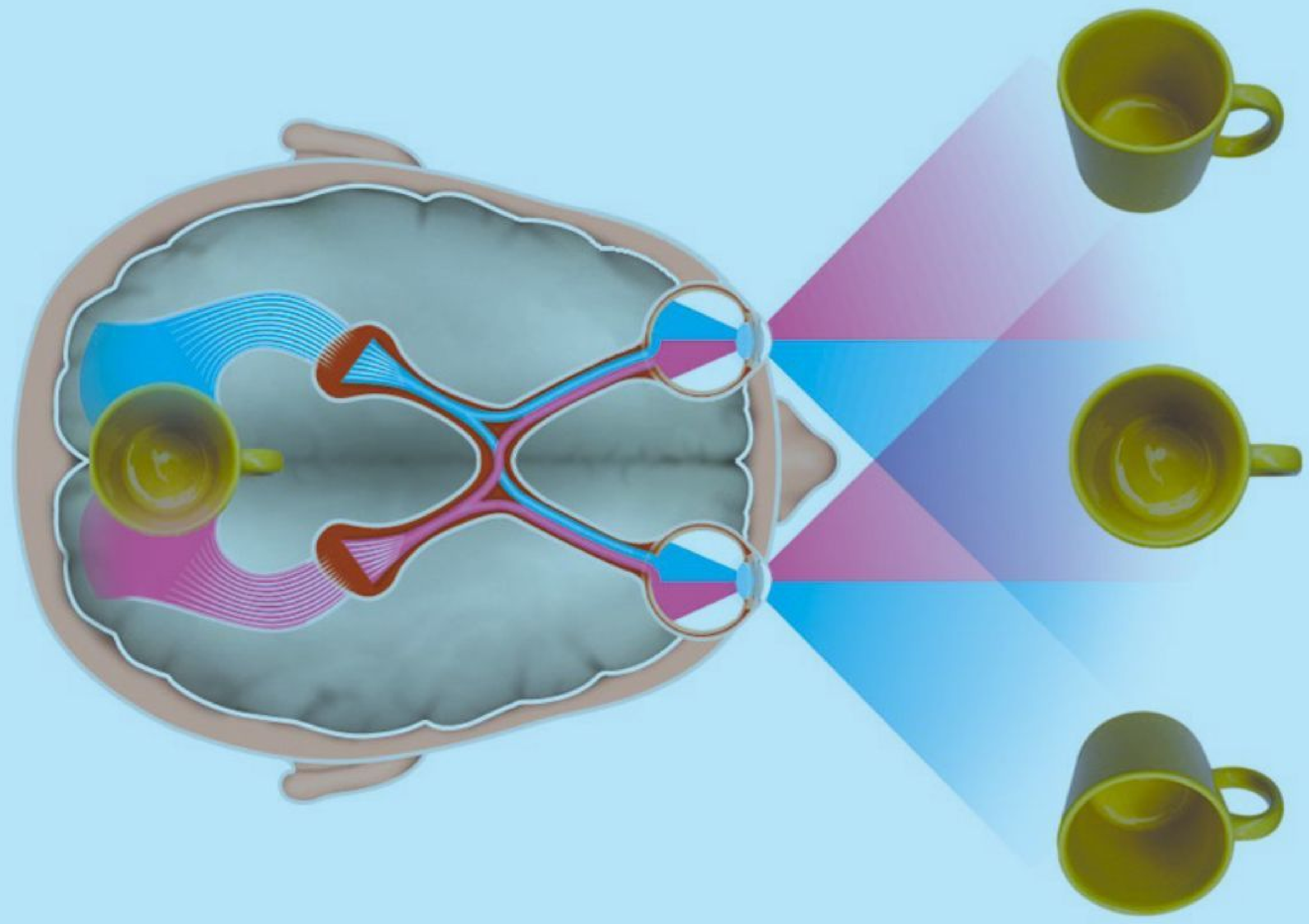
Retina
The retina is covered in receptors that detect light. It is highly pigmented, preventing the light from scattering and ensuring a crisp image.

Iris
This circular muscle controls the size of the pupil, allowing it to be closed down in bright light, or opened wide in the dark.

Seeing in three dimensions

Each eye sees a slightly different image, allowing the brain to perceive depth

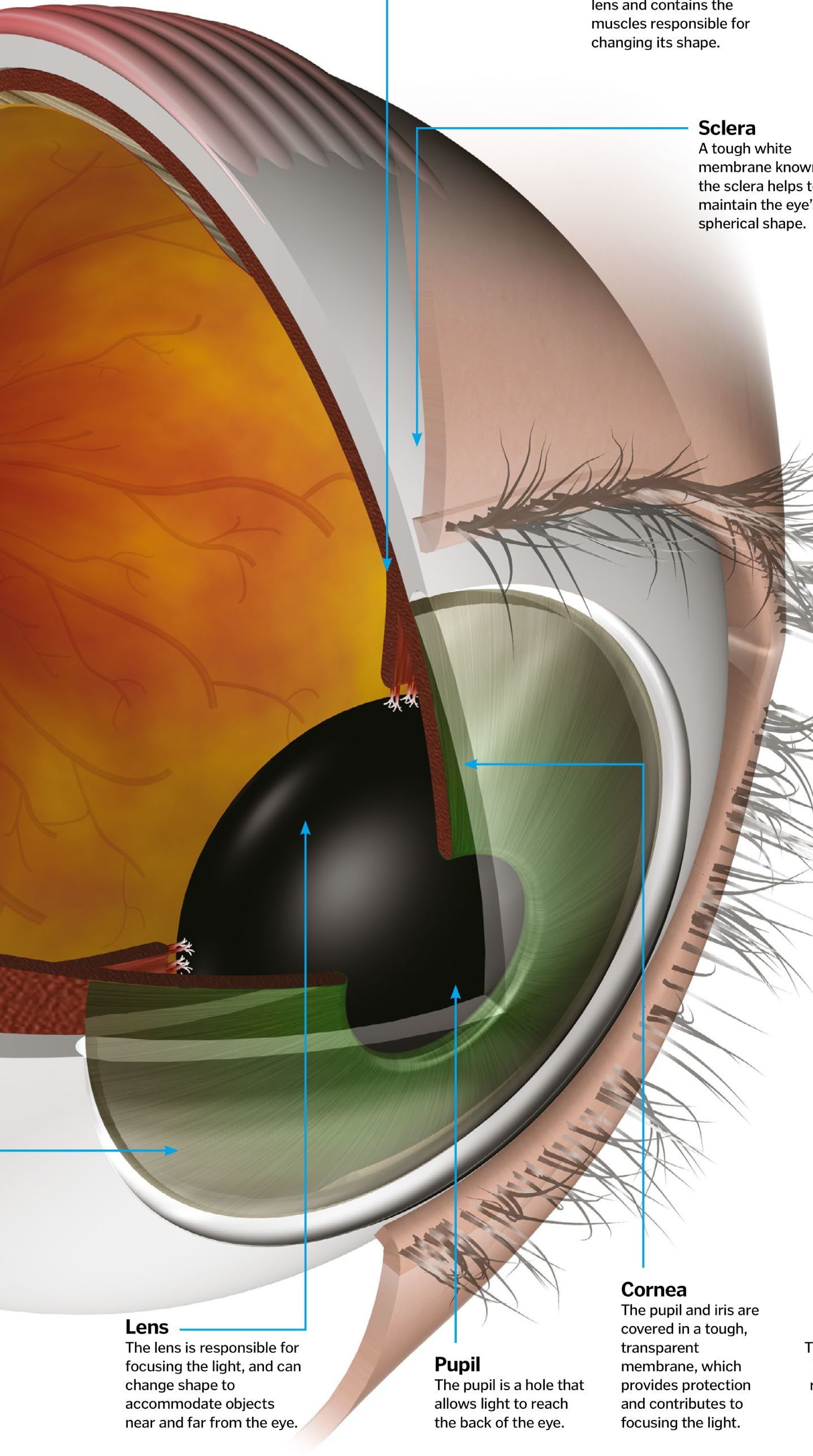
Our eyes are only able to produce two-dimensional images, but with some clever processing, the brain is able to build these flat pictures into a three-dimensional view. Our eyes are positioned about five centimetres (two inches) apart, so each sees the world from a slightly different angle. The brain compares the two pictures, using the differences to create the illusion of depth.



Individual image
Due to the positioning of our eyes, when objects are closer than about 5.5m (18ft) away, each eye sees a slightly different angle.

Combined image
The incoming signals from both eyes are compared in the brain, and the subtle differences are used to create a three-dimensional image.

Try it for yourself
By holding your hand in front of your face and closing one eye at a time, it is easy to see the different 2D views perceived by each eye.



Ciliary body
This tissue surrounds the lens and contains the muscles responsible for changing its shape.

Sclera
A tough white membrane known as the sclera helps to maintain the eye's spherical shape.

Lens
The lens is responsible for focusing the light, and can change shape to accommodate objects near and far from the eye.

Pupil
The pupil is a hole that allows light to reach the back of the eye.

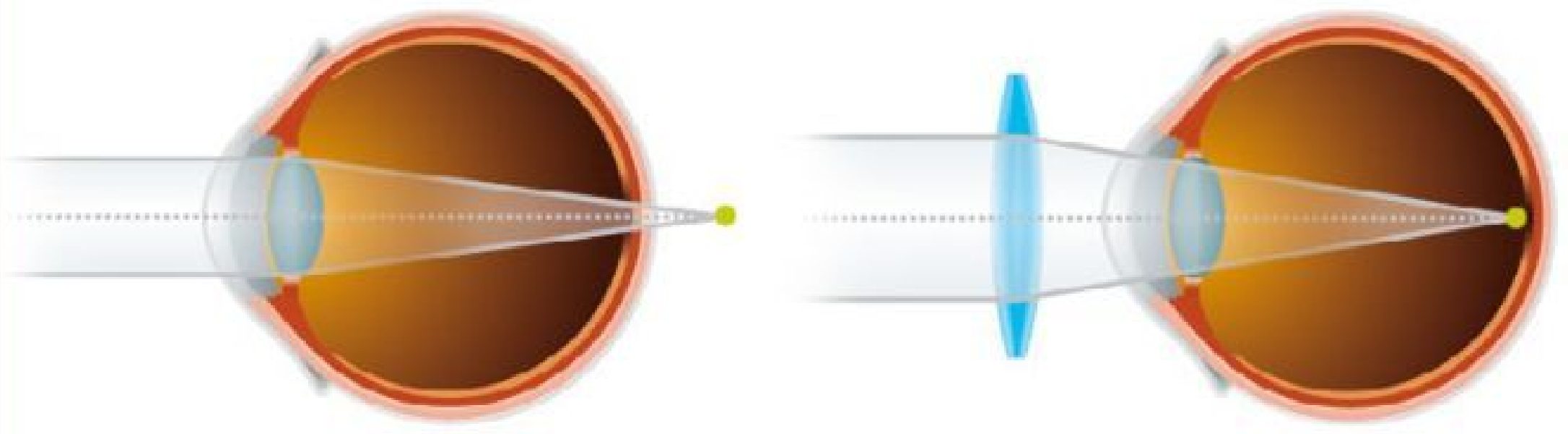
Cornea
The pupil and iris are covered in a tough, transparent membrane, which provides protection and contributes to focusing the light.

Vision problems

The most common problems with our eyesight

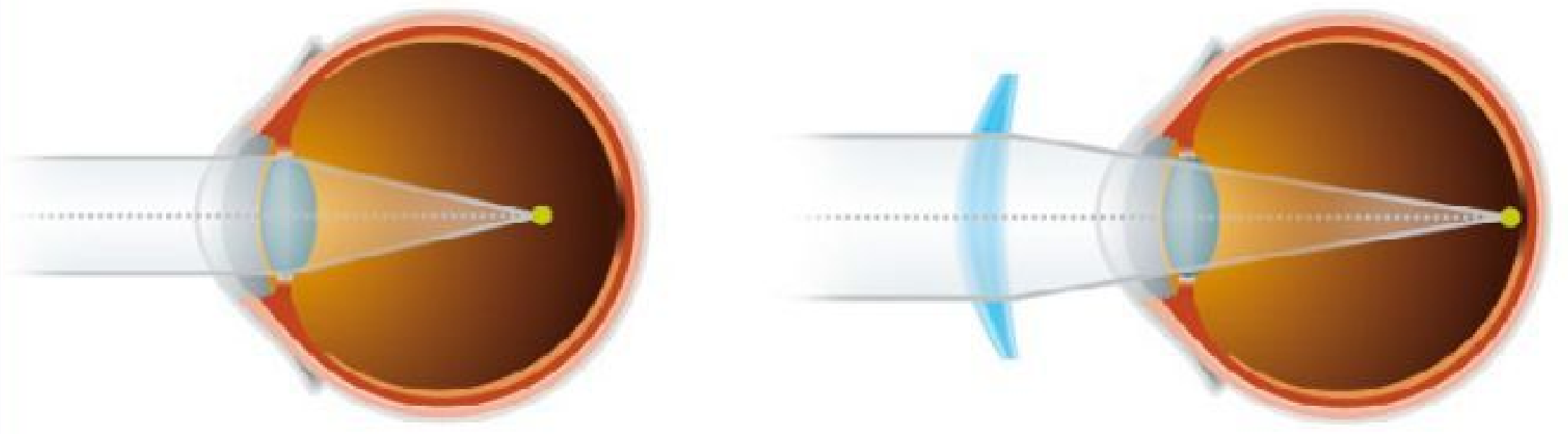
Farsightedness (hyperopia)

If the eye is too short, the cornea is too flat, or if the lens sits too far back, incoming light is focused behind the retina, making nearby objects appear blurry, particularly in the dark.



Nearsightedness (myopia)

If the eye is too long, or the cornea and lens are too curved, the light is focused before it hits the back of the eye, and then starts to defocus again as it reaches the retina, making distant objects difficult to see.

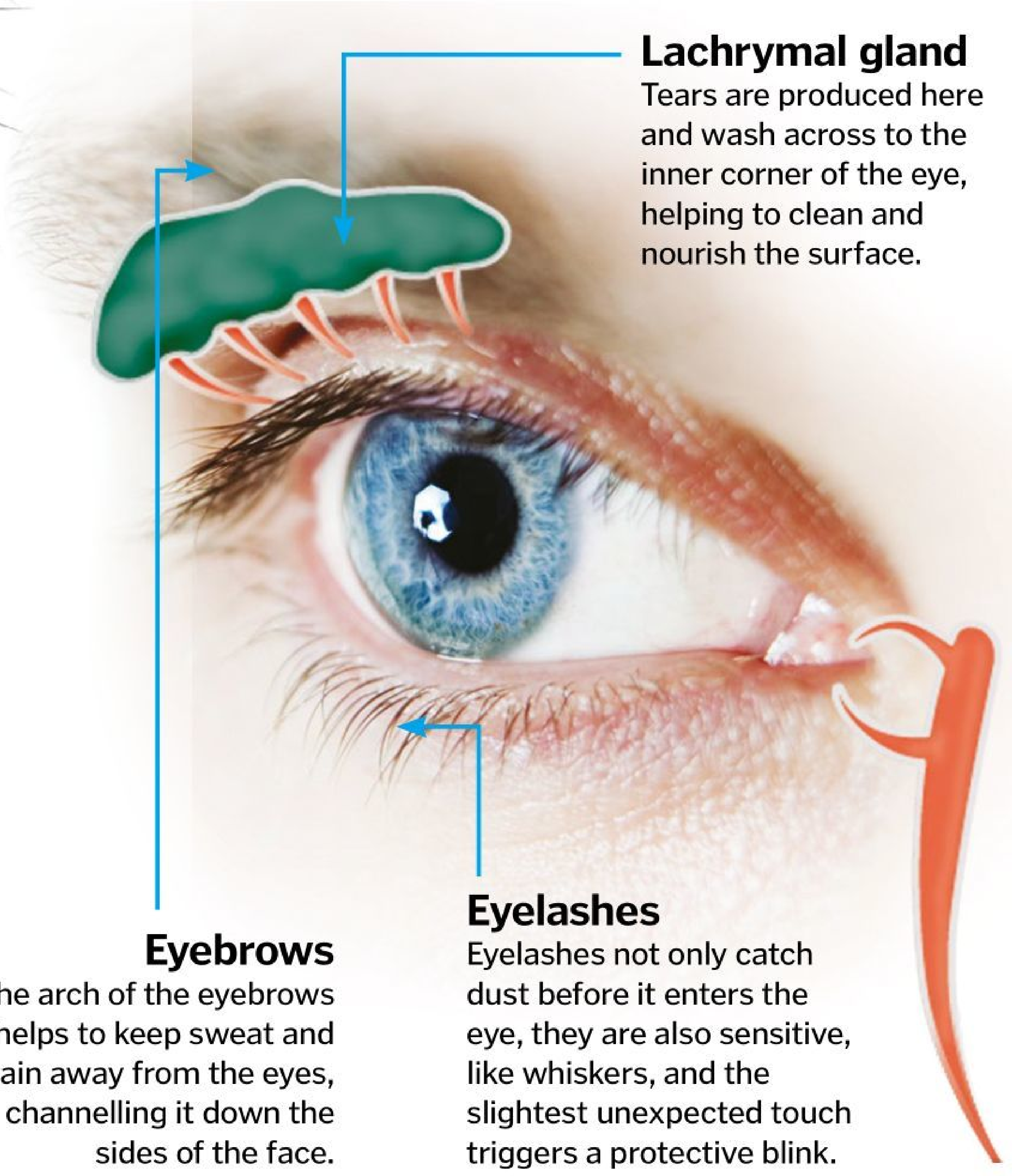


Colour-blindness

This rare condition is often linked to a gene on the X-chromosome and occurs more commonly in men than in women. A defect in the cone cells of the eye reduces the number of colours that can be detected.

Protection

The eyes are shielded by several layers of protection. They are almost completely encased in bone at the back and insulated from shock by layers of muscle and connective tissue. The front is kept moist with tears and constantly wiped by the eyelids, while the hairs of the eyebrows and eyelashes catch any debris that might fall in.



Lachrymal gland
Tears are produced here and wash across to the inner corner of the eye, helping to clean and nourish the surface.

Eyebrows
The arch of the eyebrows helps to keep sweat and rain away from the eyes, channelling it down the sides of the face.

Eyelashes
Eyelashes not only catch dust before it enters the eye, they are also sensitive, like whiskers, and the slightest unexpected touch triggers a protective blink.

Colour vision

Why humans see the world in so many colours

Night monkeys have large eyes that enhance their nocturnal vision

Open your eyes, and you are met with an array of different colours, but amazingly you can only detect three different wavelengths of light, corresponding to green, blue, and red. Combining these three signals in the brain creates millions of different shades.

Each eye has between 6 and 7 million cone cells, containing one of three colour-sensitive proteins known as opsins. When photons of light hit the opsins, they change shape, triggering a cascade that produces electrical signals, which in turn transmit the messages to the brain. Well over half of our cone cells respond to red light, around a third to green light, and just two per cent to blue light, giving us vision focused around the yellow-green region of the spectrum.

The vast majority of the cone cells in the human eye are located in the centre of the retina, on a spot known as the fovea, measuring just fractions of a millimetre across. Light is focused on this point, providing a crisp, full-colour image at the centre of our vision. The remainder of the retina is dominated by 120 million rod cells, which detect light, but not colour.

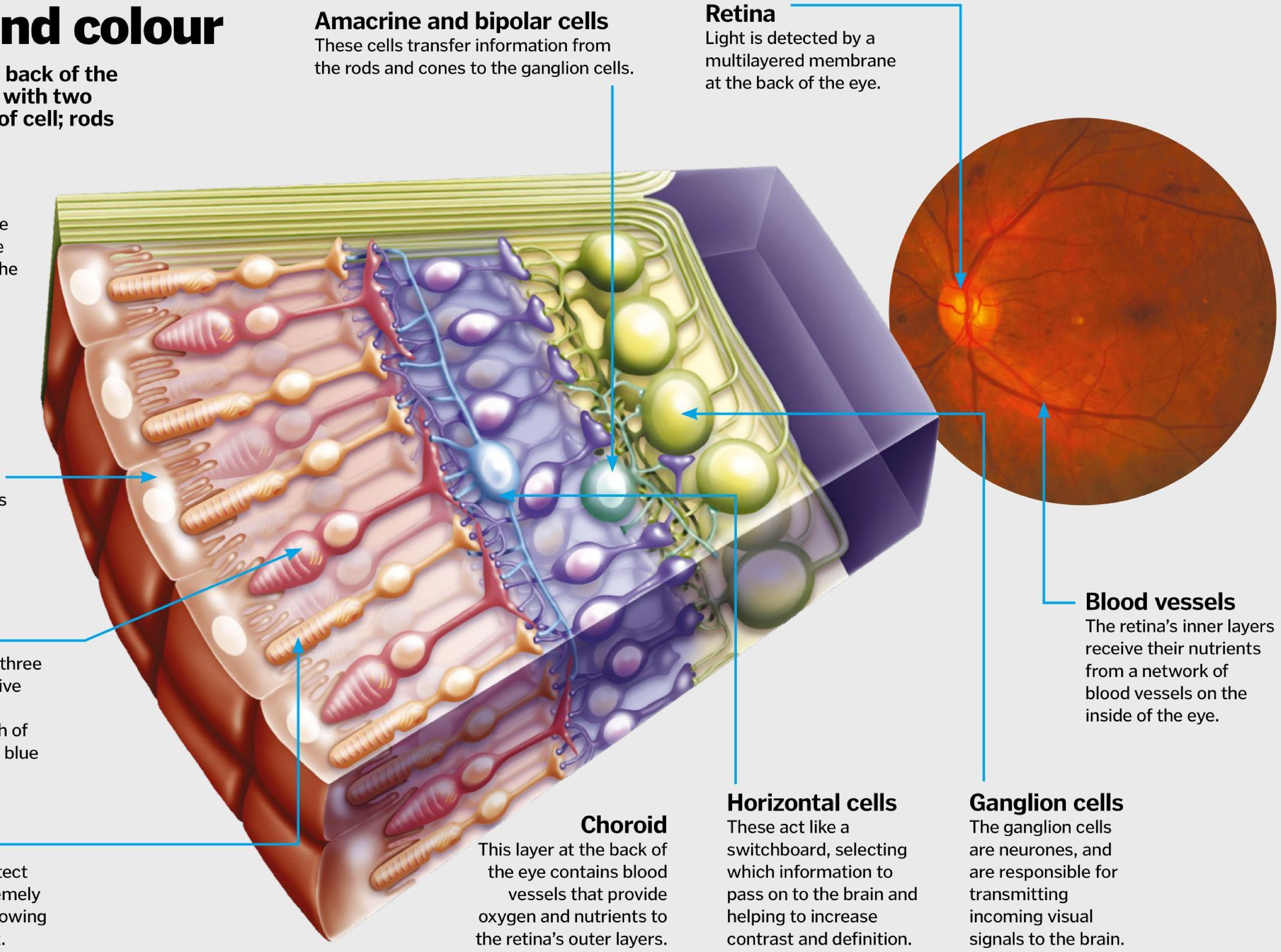
We are so used to seeing the world in red, green and blue that it might seem strange to think that most other animals cannot, but three-coloured vision like our own is relatively unusual. Some species of fish, reptiles and birds have four-colour vision, able to see red, green, blue and ultraviolet or infrared light, but during mammalian evolution, two of the four cone types were lost, leaving most modern mammals with dichromatic vision – seeing in shades of just yellow and blue.

This was not a problem for many early mammals, because they were largely nocturnal, and lived underground, where there was little need for good colour vision. However, when primates started moving into the trees, a gene duplication gave some species the ability to see red, providing a significant evolutionary advantage in picking out ripe red fruit against the green leaves.

Even today, not all primates can see in three colours; some have dichromatic vision, and many nocturnal monkeys only see in black and white. It is all down to environment; if you don't need to see all of the colours in order to survive, then why waste energy making the pigments?

Light and colour

As light hits the back of the eye, it interacts with two different types of cell; rods and cones



Amacrine and bipolar cells
These cells transfer information from the rods and cones to the ganglion cells.

Retina
Light is detected by a multilayered membrane at the back of the eye.

Sclera
The white part of the eye continues all the way to the back of the retina, providing structural support.

Pigment epithelium
This dense sheet of cells contains dark pigment granules, which absorb excess light, preventing it from scattering inside the eye.

Cone cell
The human eye has three types of light-sensitive cone cell, each for a different wavelength of light, red, green and blue respectively.

Rod cell
Rod cells cannot detect colour, but are extremely sensitive to light, allowing us to see in the dark.

Choroid
This layer at the back of the eye contains blood vessels that provide oxygen and nutrients to the retina's outer layers.

Horizontal cells
These act like a switchboard, selecting which information to pass on to the brain and helping to increase contrast and definition.

Ganglion cells
The ganglion cells are neurones, and are responsible for transmitting incoming visual signals to the brain.

Blood vessels
The retina's inner layers receive their nutrients from a network of blood vessels on the inside of the eye.

DID YOU KNOW? *The eye muscles are the most active muscles in the body. They move more than 100,000 times a day*

How we see

Look around you – do you know what you're seeing with?

The back of the eye is covered in a layer of light-sensitive cells measuring just fractions of a millimetre in thickness. When photons of light hit the pigments inside the cells, it triggers a cascade of signals, which pass through a series of different connections before they are transmitted to the brain.

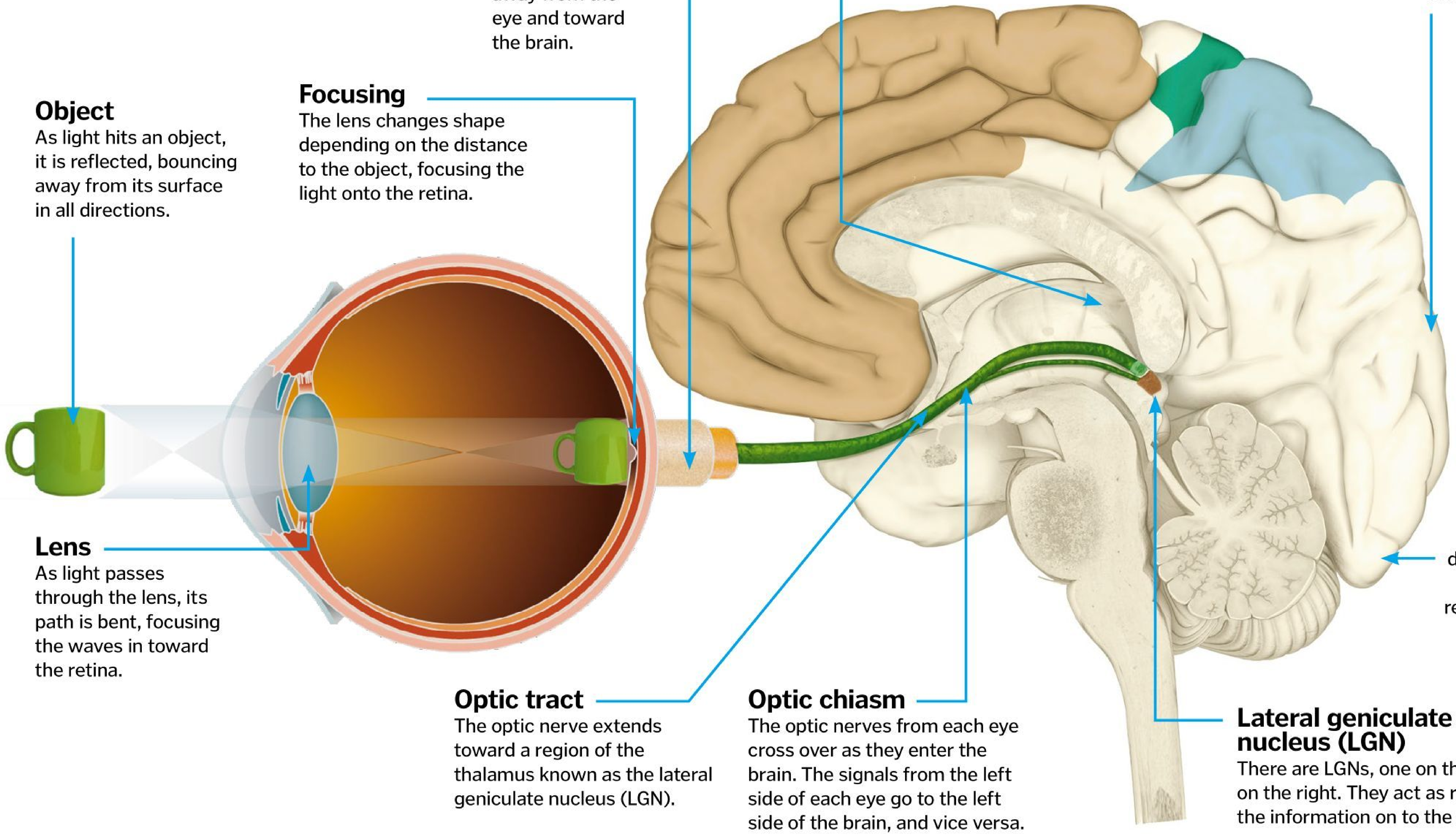
First, they move through interneurones and then to neurones known as ganglion cells. These cells are cross-linked, able to compare adjacent signals, filtering out some of the information before passing it on to the brain. This helps to improve contrast and definition. The neurones travel across the back surface toward the optic nerve, which relays the information into the brain.

As the two optic nerves enter the brain, they cross over, coming together at a point known as the optic chiasm. Here, signals from the left side of both eyes are diverted to the left side of the brain, and vice versa, allowing the images from both eyes to be combined and compared.

The signals enter the brain via the thalamus, which separates the incoming information into two parts, one containing colour and detail, and the other movement and contrast. The messages then move to the back of the brain, and into the visual cortex. The cortex is laid out so that it mirrors the back of the retina, allowing a detailed image to be reconstructed.

Optic nerve

Information from the light-sensitive cells in the eyes is passed to the brain via the optic nerve



Object
As light hits an object, it is reflected, bouncing away from its surface in all directions.

Focusing
The lens changes shape depending on the distance to the object, focusing the light onto the retina.

Optic nerve
The optic nerve carries signals away from the eye and toward the brain.

Thalamus
The thalamus is situated deep inside the brain, involved in relaying sensory information, including vision, hearing and touch.

Visual cortex
The visual cortex made up of six separate parts, located right at the back of the brain.

Lens
As light passes through the lens, its path is bent, focusing the waves in toward the retina.

Primary visual cortex
Arranged like a map of the retina, it has a large area dedicated to the fovea – the region of the eye responsible for detailed colour vision.

Optic tract
The optic nerve extends toward a region of the thalamus known as the lateral geniculate nucleus (LGN).

Optic chiasm
The optic nerves from each eye cross over as they enter the brain. The signals from the left side of each eye go to the left side of the brain, and vice versa.

Lateral geniculate nucleus (LGN)
There are LGNs, one on the left, and one on the right. They act as relays and send the information on to the visual cortex.

Quick-fire questions

Why do we see in black and white at night?

The colour-sensitive cone cells in the eye function like slow camera film – they produce highly detailed images, but require lots of light to work. In contrast, light-sensitive rod cells are like fast film. They respond to low levels of light, but cannot detect colour, producing a grainy, black-and-white image.

Why does our eyesight get worse as we get older?

As the eye ages, the lens becomes less flexible, making it increasingly difficult to focus on nearby objects. Luckily, this is easily corrected with glasses. Cloudy areas, known as cataracts, can also start to appear within the lens, making vision appear blurred or misty, but this can often be fixed with simple surgery.

Why do our eyes jump instead of moving around smoothly?

Movement of the eye is controlled by the brainstem. Our vision would be blurry if our eyes moved smoothly, so they jump in steps known as saccades. The brain stitches the images together, like the frames in a film, producing the illusion of continuous movement.

Why do some animals have their eyes on the sides of their head?

Forward-facing eyes are incredibly useful for primates, who need to be able to accurately judge depth when jumping between trees, for example, and for predators who need to pinpoint their prey. In contrast, prey animals need to be able to watch for danger, and often sacrifice binocular vision for a more rounded view of their environment.

The retina

How does this photosensitive layer enable us to see pictures?

The retina is a special type of light-sensitive tissue located in the interior of the eye that's so analogous to brain tissue, it's considered a part of the central nervous system. If you consider our eyes to be cameras, then the retina is the film. However, the retina does much more than just send a 'picture' to the brain – it actually has to compress the image so that it can be conveyed via the optic nerve, because the photoreceptors in the retina can take in more information than the optic nerve can convey.

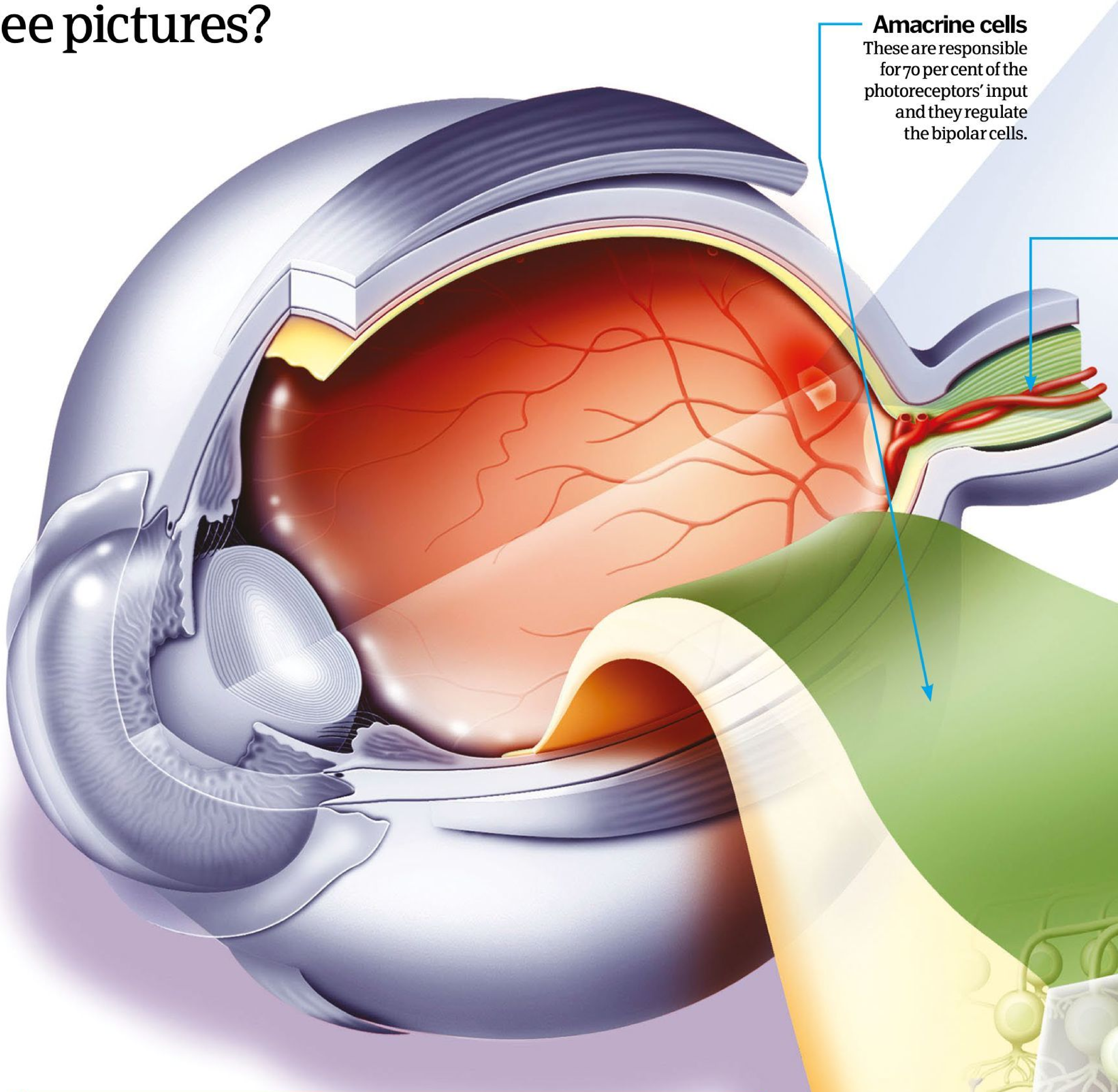
Although it looks like a single layer, the retina is actually very complex and comprises ten layers of nerve cells, all of which are connected by synapses. Within each of these layers are several different types of cells: the photoreceptors called rods and cones, photosensitive ganglion cells, bipolar cells and other cells that assist with regulating light input as well as processing and transmitting images. Rods and cones each have their own function. Rods are more sensitive to light and are responsible for night vision and peripheral vision; each one can respond to a single photon, or particle, of light. Cones, on the other hand, work in bright light and are responsible for seeing colour, fine detail and rapid movements.

Until the Nineties, it was thought that only rods and cones were involved in sight. Then researchers discovered a much rarer type of cell called photosensitive ganglion cells. These cells help regulate pupil size and the light/dark cycle, or circadian rhythms, that we function by.

Light reaches the rods and cones by first passing through transparent layers of nerve cells. When it reaches these photoreceptors, the light causes chemical changes in the rods and cones. The raw data is sent back through the layers of nerve cells, which process and encode the image before sending it via the optic nerve to the brain.

Retina anatomy

The eye is one of the most complex structures in the body – and the retina plays a vital role…



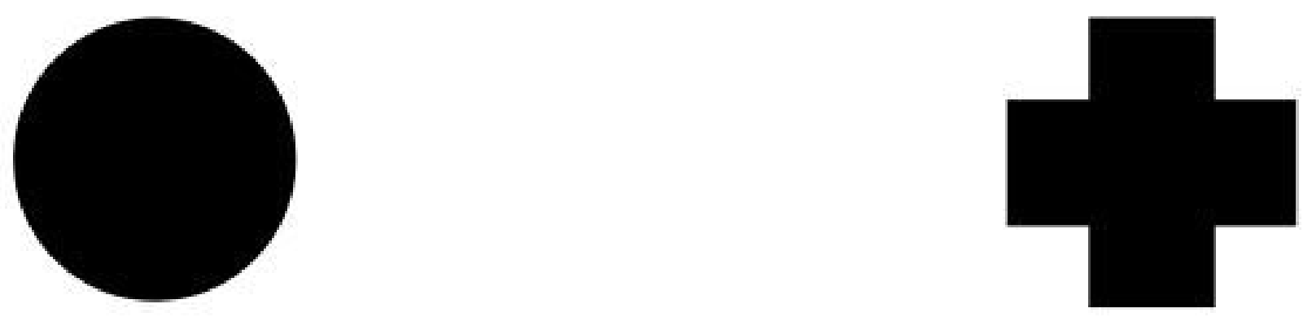
Amacrine cells
These are responsible for 70 per cent of the photoreceptors' input and they regulate the bipolar cells.

Macula
This yellow-coloured area of the retina contains a high concentration of cone cells that are responsible for sharpness of vision.

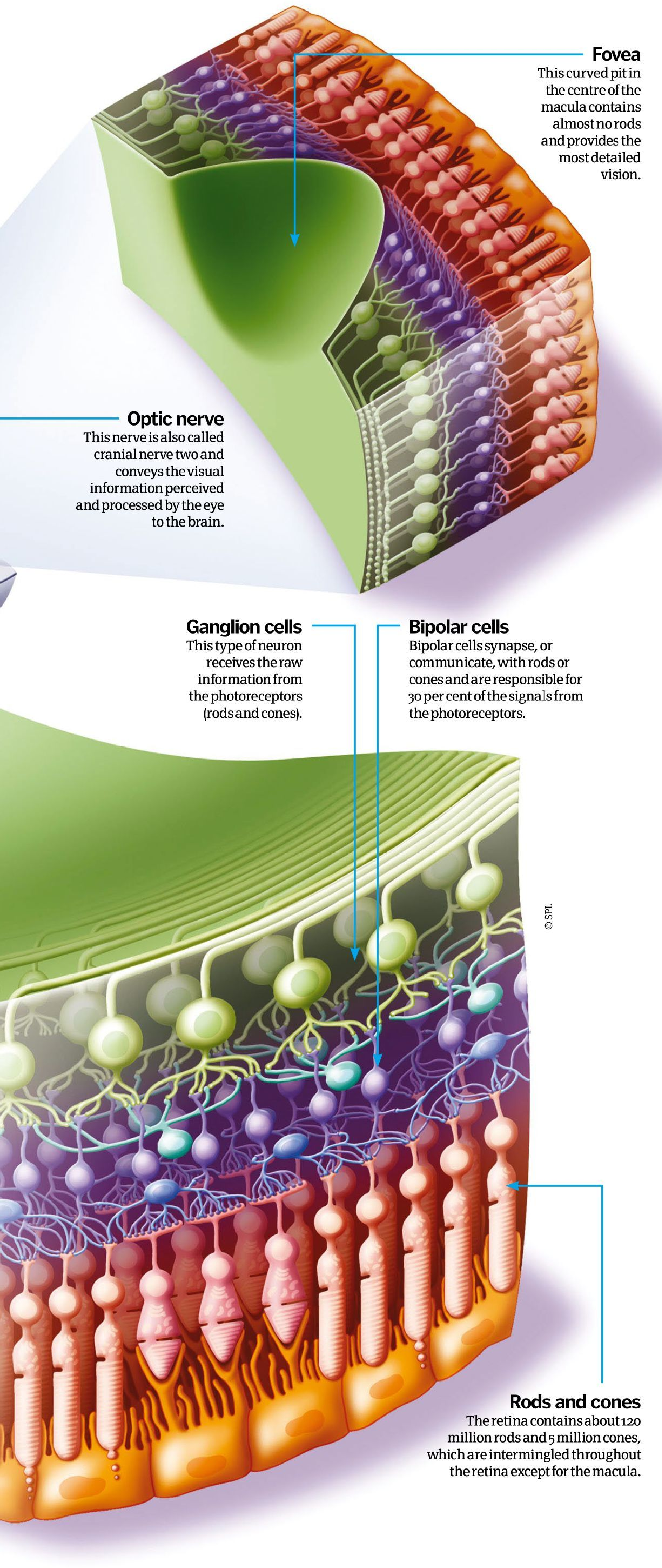
Blind spot

We all have a blind spot, or scotoma – a place on the retina where there are no photoreceptive cells to perceive light. Known as the optic disc, this area is where the optic nerve passes through the retina on the way to the brain. Although the blind spot is sizeable, we don't notice it. That's because the blind spot in each eye is in a different place, so the other eye 'fills in' the blanks. To the right we have included a 'blind spot test'. When you close your left eye and focus on the circle, then slowly get closer to the page, the plus sign will vanish!

THE BLIND SPOT TEST



DID YOU KNOW? *Octopus eyes have nerves attached to the rear of the retina, meaning they don't have a blind spot like humans*



Fovea
This curved pit in the centre of the macula contains almost no rods and provides the most detailed vision.

Optic nerve
This nerve is also called cranial nerve two and conveys the visual information perceived and processed by the eye to the brain.

Ganglion cells
This type of neuron receives the raw information from the photoreceptors (rods and cones).

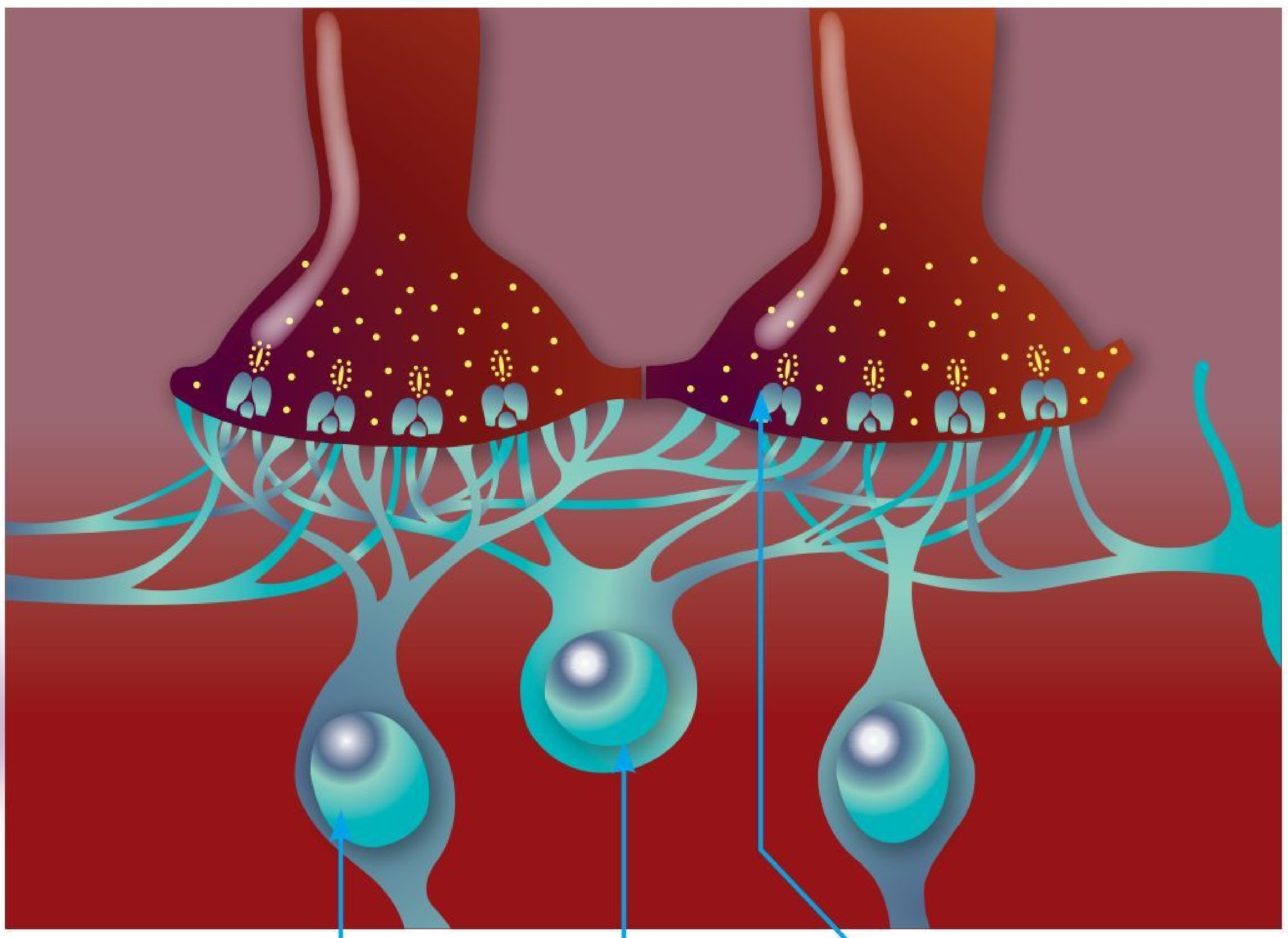
Bipolar cells
Bipolar cells synapse, or communicate, with rods or cones and are responsible for 30 per cent of the signals from the photoreceptors.

Rods and cones
The retina contains about 120 million rods and 5 million cones, which are intermingled throughout the retina except for the macula.

© SPL

Synapses

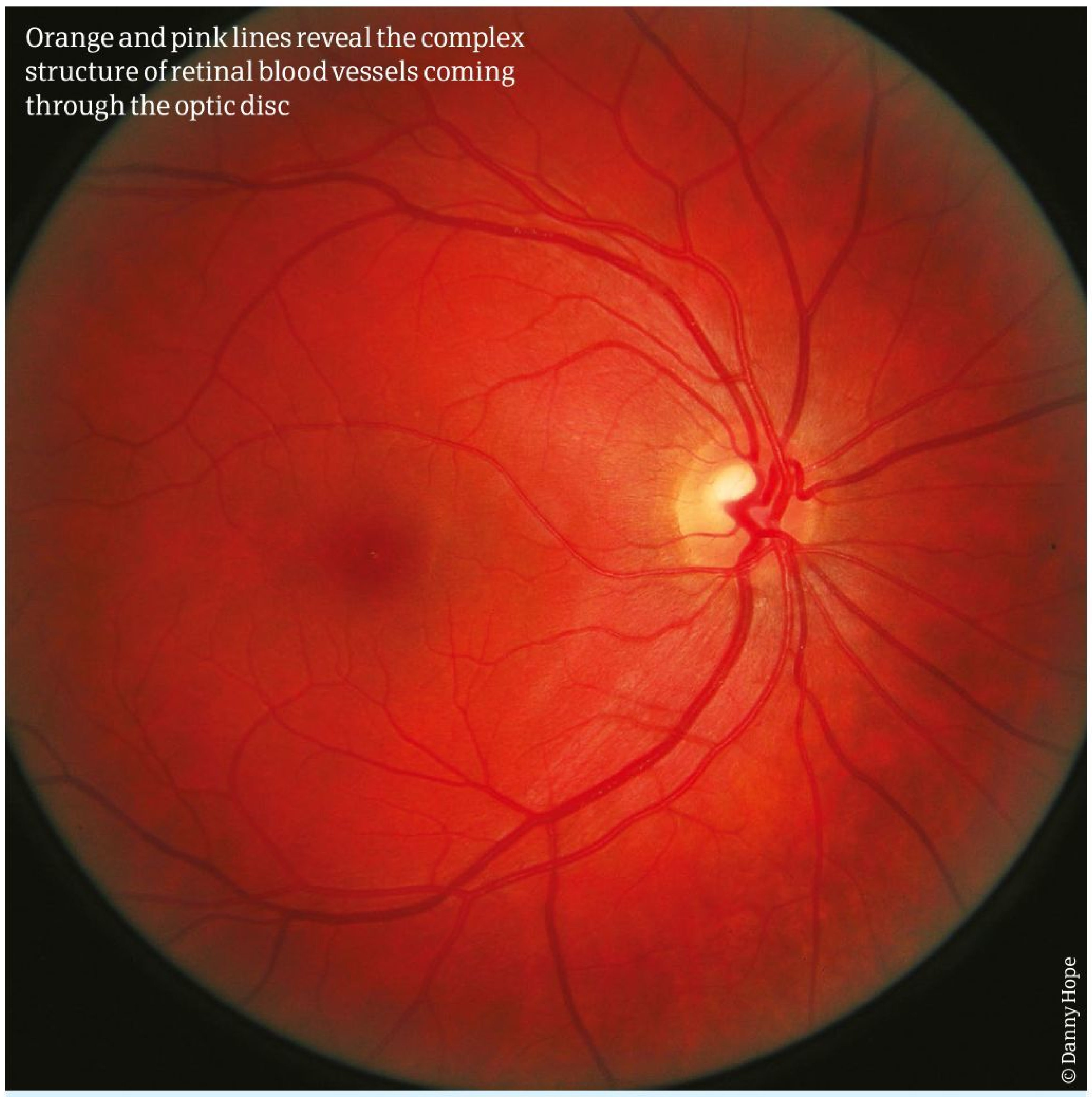
Neurons work together to combine data from rod and cone cells into messages that travel to the brain



Bipolar cells
Each bipolar cell corresponds to a specific cone or rod cell.

Horizontal cells
These neurons interconnect different types of photoreceptors and also regulate their function.

Photoreceptors
Rods and cones each transmit their own input during the vision process.



Orange and pink lines reveal the complex structure of retinal blood vessels coming through the optic disc

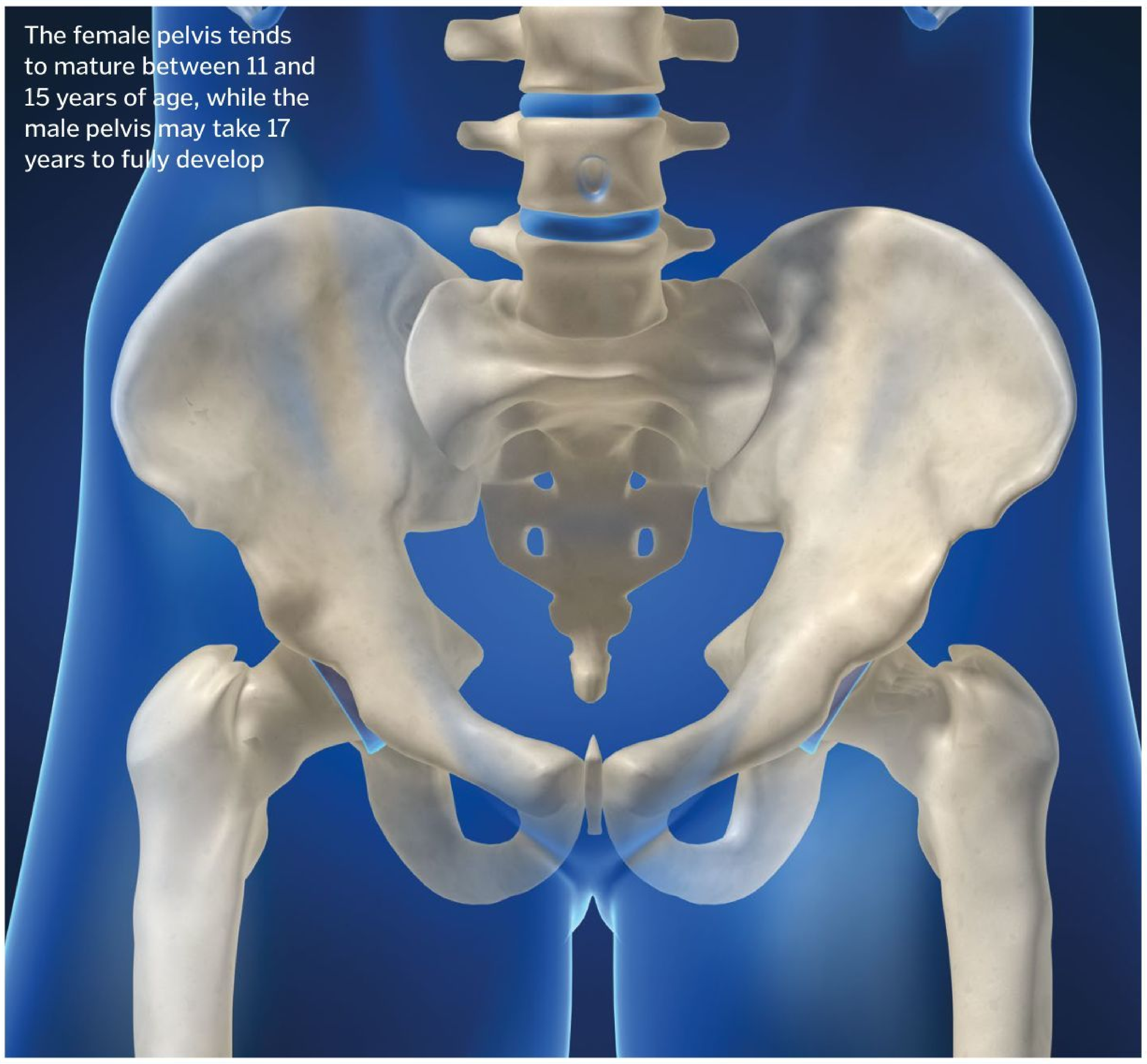
© Danny Hope

Retinal scan

Iris scanning is the more common form of biometrics when it comes to eyes, but did you know that our retinas also have special identifying characteristics? It all comes down to the complex network of blood vessels in the retina; even twins' retinas are different. When you look into a retinal scanner, a low-energy beam of infrared light is reflected by the capillaries. The resulting unique pattern is then stored as code within a database. Retinal scanners are fast and reliable, but the downside is that the scanners are expensive and the pattern can change over time with certain diseases or other eye problems.

The human pelvis

Linking our upper and lower body, this basin-shaped complex of bones is essential for getting around



The female pelvis tends to mature between 11 and 15 years of age, while the male pelvis may take 17 years to fully develop

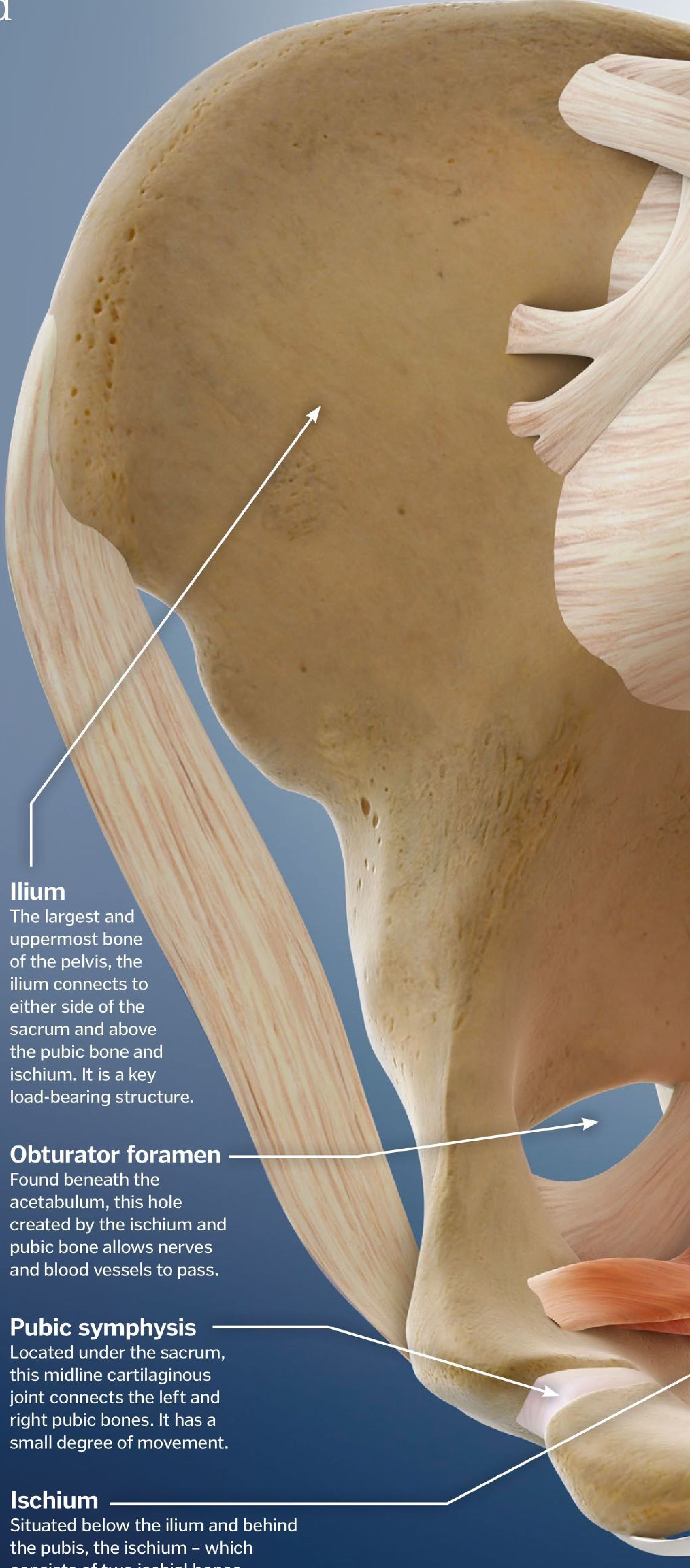
The pelvis is an essential part of the skeleton which acts as a junction between the abdomen and the legs. It consists of eight key structures: the sacrum, ilium, ischium, pubic bone, pubic symphysis, obturator foramen, acetabulum and coccyx, which are laid out symmetrically. Together these make up the bony pelvis.

The role of the pelvis is threefold. Firstly, it serves as a connecting mechanism between the torso and the legs. Secondly, it is a vital support and balance structure for the upper body. And thirdly it provides a protective, containing cradle for the intestines, bladder and internal sex organs.

The pelvis – technically referred to as the pelvic girdle in this context – consists of a pair of hipbones connected to the base of the vertebral column. Each hipbone is formed from the fusing of three smaller bones (the ilium, ischium and pubic bone) that, when combined, link the base of the spine (the sacrum) to the lower limbs via the acetabula – the cup-shaped cavities into which the femurs fit via ball-and-socket joints.

The pelvic girdle, when fully formed, resembles a roughly cylindrical basin, or the pelvic cavity, perforated on the underside with two main sets of holes. These are the aforementioned acetabula, as well as the obturator foramina, the former receiving the thighbones (femurs) and the latter allowing for the passage of nerves and blood vessels between the torso and the lower body.

Interestingly, in infants the pelvis is a far narrower structure than at full maturity, offering little – if any – support. This changes as we grow, with the pelvis broadening and tilting under the influence of increased walking and standing. When it is fully formed, the human pelvic skeleton can comprise more than ten bones, with the number determined by the composition of the individual's tailbone (coccyx). This structure is composed of three to five successively smaller caudal vertebrae located at the base of the sacrum.



Ilium
The largest and uppermost bone of the pelvis, the ilium connects to either side of the sacrum and above the pubic bone and ischium. It is a key load-bearing structure.

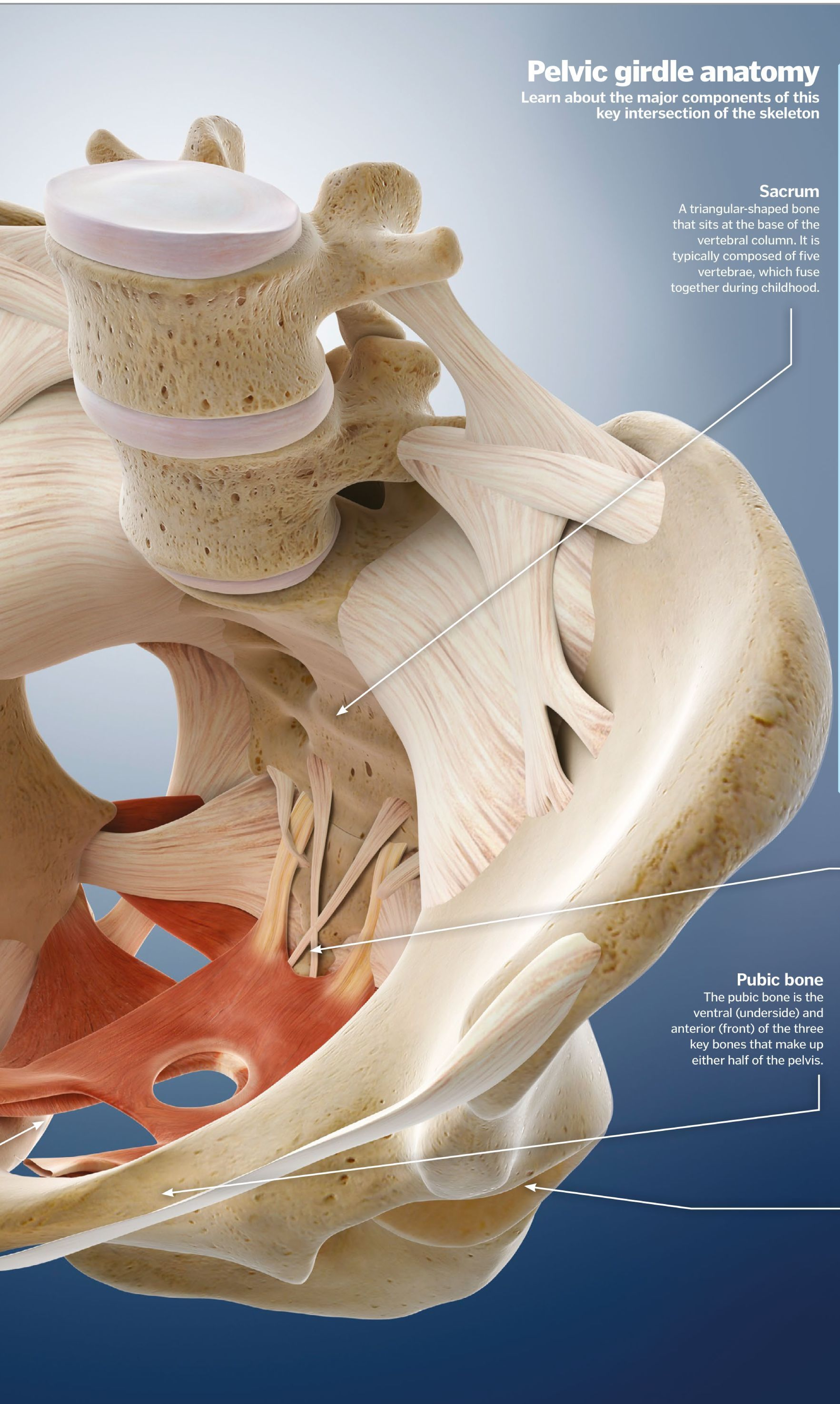
Obturator foramen
Found beneath the acetabulum, this hole created by the ischium and pubic bone allows nerves and blood vessels to pass.

Pubic symphysis
Located under the sacrum, this midline cartilaginous joint connects the left and right pubic bones. It has a small degree of movement.

Ischium
Situated below the ilium and behind the pubis, the ischium – which consists of two ischial bones – takes the weight of the upper torso when in a seated position.

Pelvic girdle anatomy

Learn about the major components of this key intersection of the skeleton



Sacrum

A triangular-shaped bone that sits at the base of the vertebral column. It is typically composed of five vertebrae, which fuse together during childhood.

Coccyx

The tailbone is a curved, semi-flexible structure located at the lower end of the spine. It is made up of three to five successively smaller caudal vertebrae.

Pubic bone

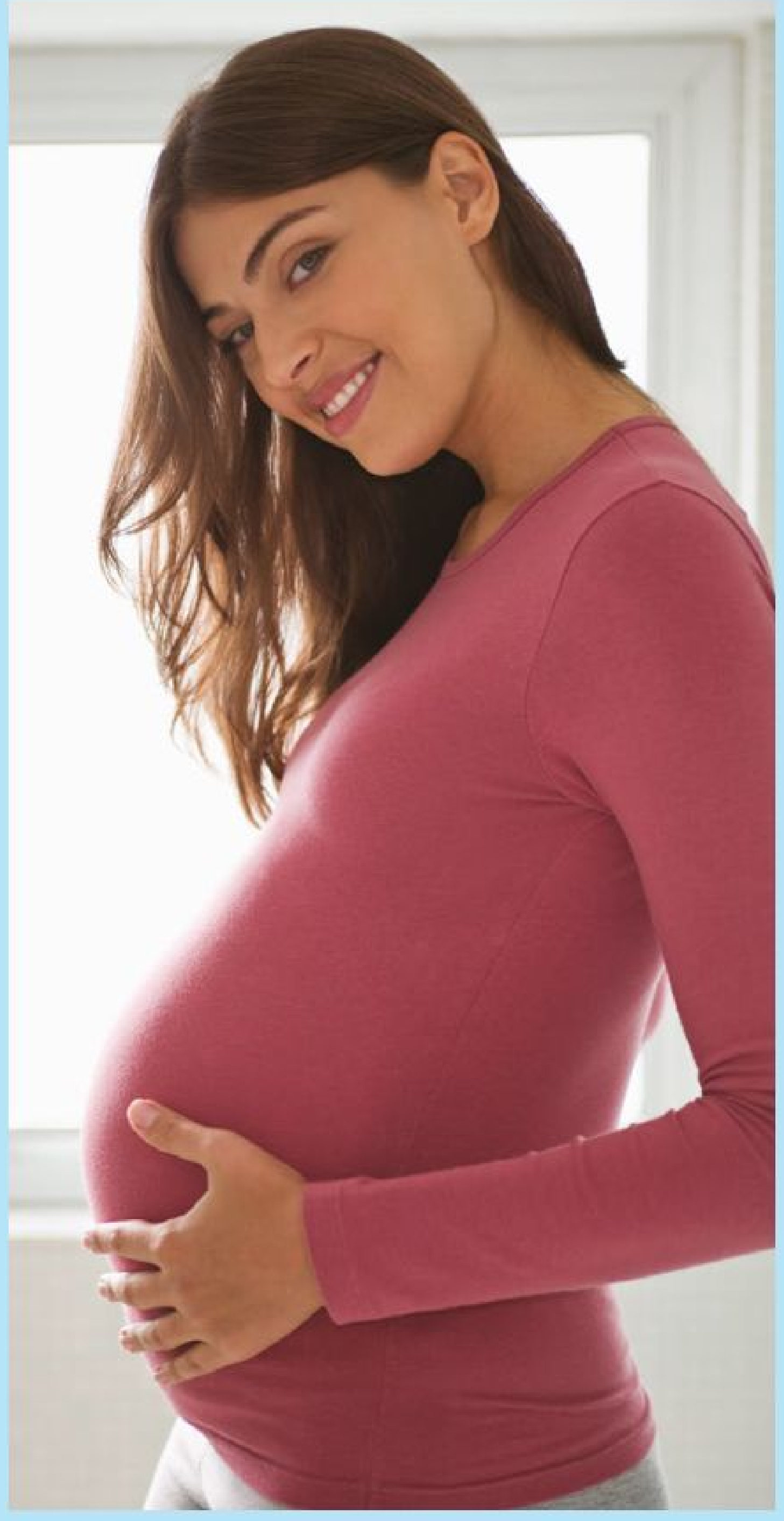
The pubic bone is the ventral (underside) and anterior (front) of the three key bones that make up either half of the pelvis.

Acetabulum

A concave surface within the lower pelvis, the acetabula are two deep cavities into which the top of the femurs sit on either side of the pelvis.

Male vs female

Differences between the male and female pelvis are numerous and stem, primarily, from the female's reproductive system. For example, the female pelvic basin is broader than the male equivalent, the pubic symphysis short and the pubic bones connect in a wider angle with each other. In addition, the coccyx has a greater degree of movement and the two acetabula are spaced farther apart. All together these allow a rounded and spacious birth canal – which hasn't been an evolutionary priority in the male of the species.



© Thinkstock; SPL

The lymphatic system

Learn what role our lymphatic system plays in keeping nasty bugs at bay

The red blood cells that carry oxygen around our bodies travel through blood vessels suspended in fluid known as plasma. It moves through vessels at such pressure that plasma can leak into the tissues. The lymphatic system helps remove it from the tissues and return it to the circulation.

The lymphatic system is similar to the circulatory system, in that it is composed of a series of vessels, found mostly in the skin and around internal organs. But the tubes do not make a circuit and there is no pump. The fluid, known as lymph, relies on the contraction of nearby muscles to return to the circulation at the subclavian veins near the collarbones.

The lymphatic system is also a transport route for the immune system. At intervals along the lymphatic vessels are between around 600 and 700 lymph nodes. Larger organs like the spleen and thymus are also connected to the network.

These organs manage immune surveillance; if an antigen-presenting cell (APC) of the immune system encounters a pathogen, it will return to the nearest lymph node with intel about the intruder. The specialist attack cells of the immune system, lymphocytes, circulate through the lymphatic system, scanning for matching patterns and, if one is found, they use the lymph node as a base to adapt until an army of enemy-specific clones is created.

Swollen lymph glands are often a sure sign of infection or disease

When the lymphatic system goes wrong

One of the most common problems associated with the lymphatic system is blockage. If any of the vessels becomes occluded, fluid cannot be properly drained from the tissues and from that point it begins to accumulate. This condition, medically known as lymphoedema, results in a buildup of fluid in the limbs, causing swelling.

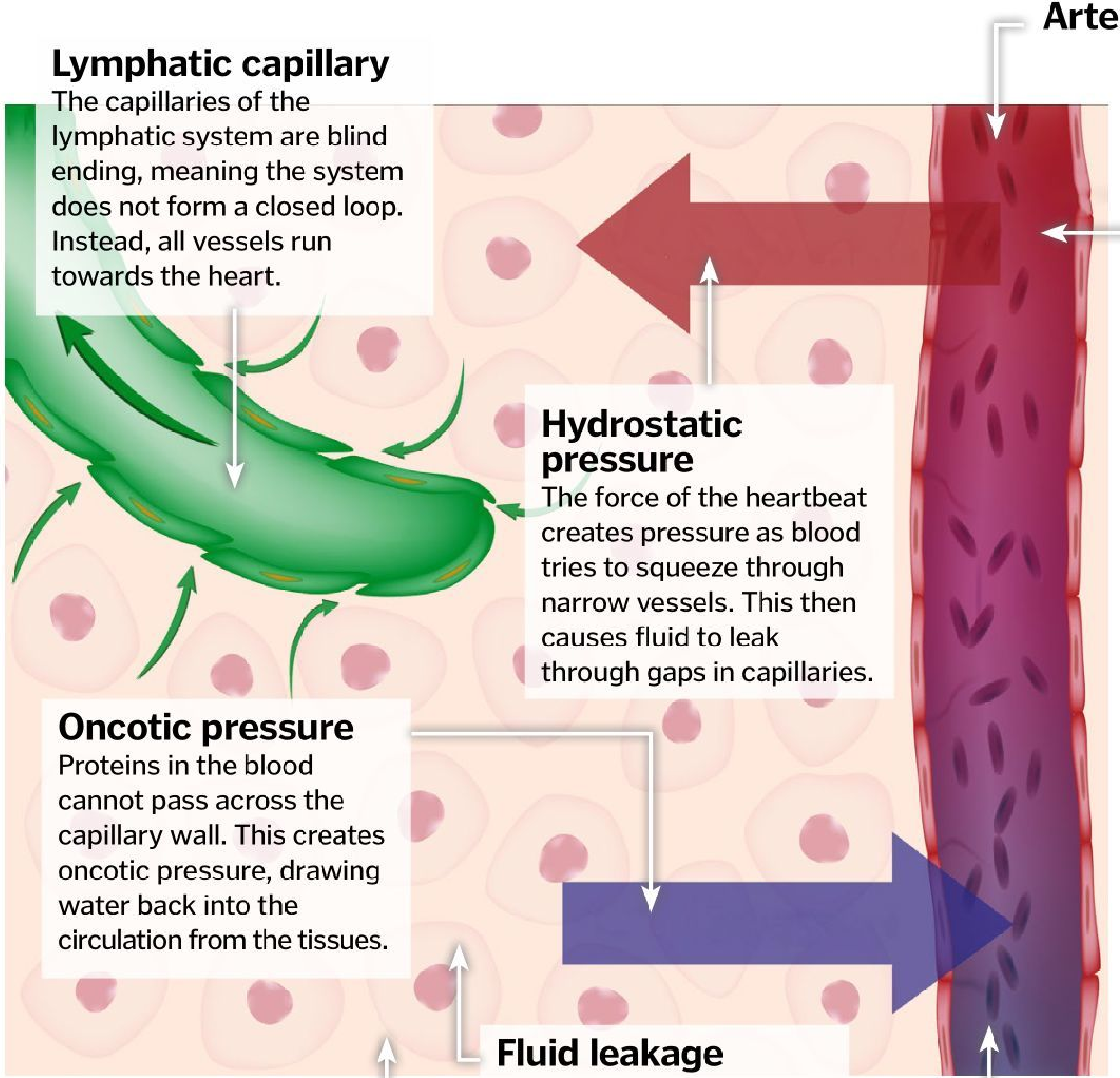
Certain species of parasitic worm rely on the human lymphatic system for part of their life cycle, and the presence of a worm infection can be one cause of lymphoedema. This is further complicated by the immune system, which responds to the worms, and any bacteria they might be infected with, leading to thickening of the skin and a condition known as elephantiasis.

Illness also affects the lymph nodes, which become swollen during infection as immune cells divide. Sometimes, cancerous transformation occurs in one of the immune cells, leading to lymphoma and eventually forming a tumour in the node.

DID YOU KNOW? *As lymph travels through the lymph nodes it picks up immune cells, which then return to the blood*

Capillary fluid exchange in action

See how lymph is transferred between the circulatory and lymphatic systems

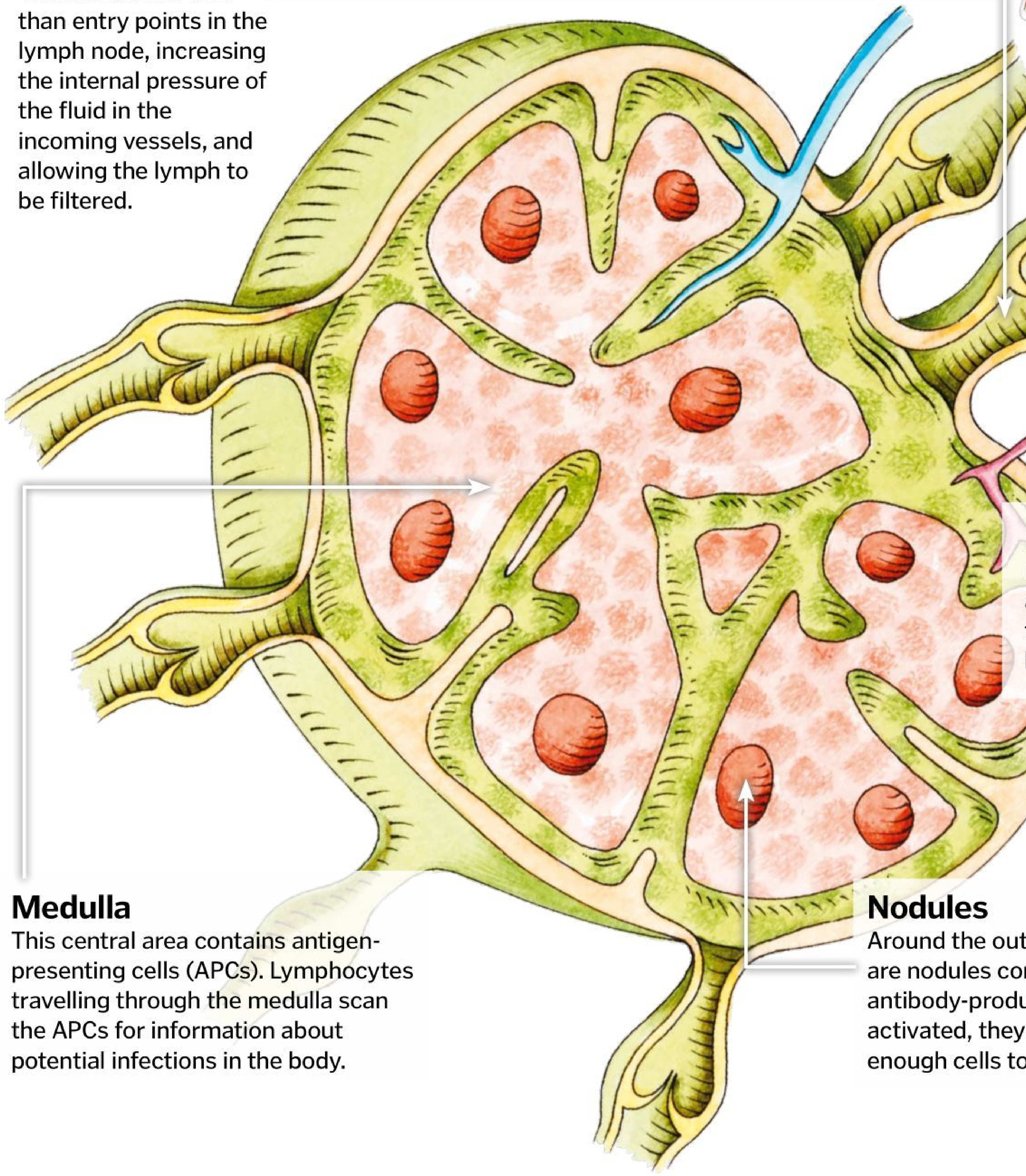


Lymphatic capillary
The capillaries of the lymphatic system are blind ending, meaning the system does not form a closed loop. Instead, all vessels run towards the heart.

Hydrostatic pressure
The force of the heartbeat creates pressure as blood tries to squeeze through narrow vessels. This then causes fluid to leak through gaps in capillaries.

Oncotic pressure
Proteins in the blood cannot pass across the capillary wall. This creates oncotic pressure, drawing water back into the circulation from the tissues.

Fluid leakage
Most fluid that leaks out of the circulation is recaptured by the effects of oncotic pressure. Any that remains enters the lymphatic system.

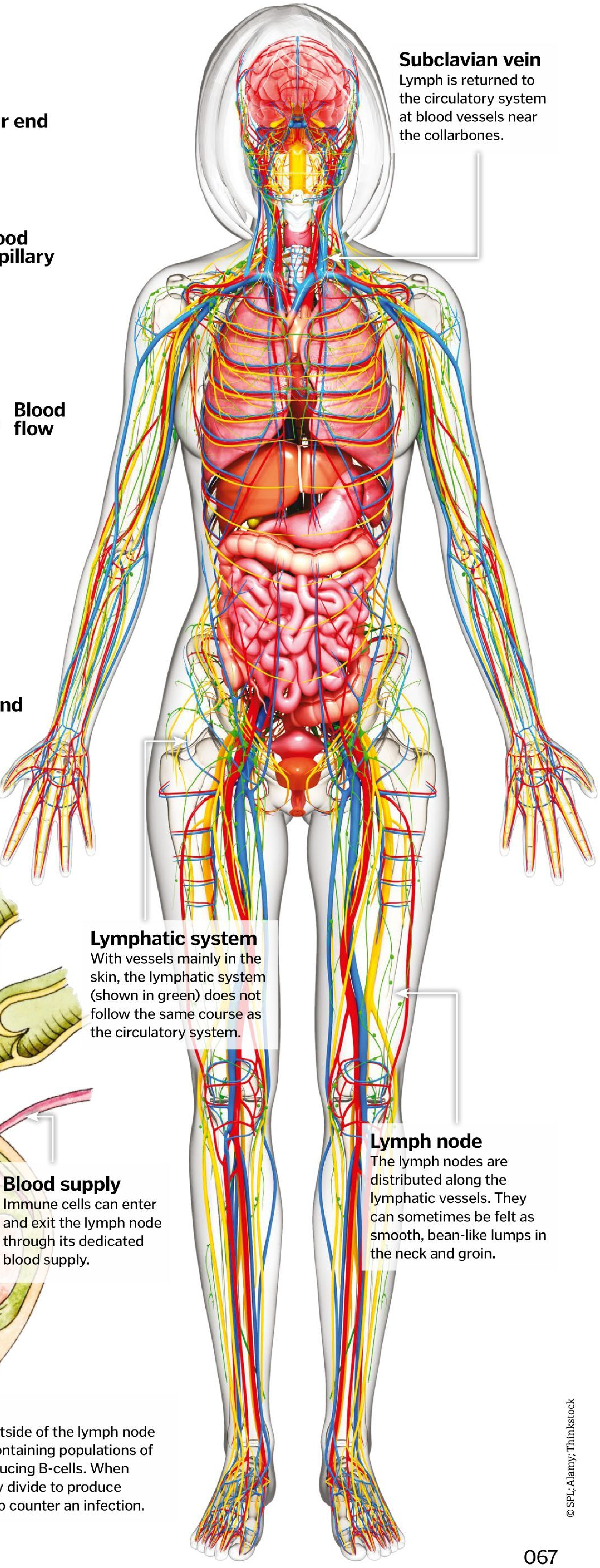


Efferent vessel
There are fewer exit than entry points in the lymph node, increasing the internal pressure of the fluid in the incoming vessels, and allowing the lymph to be filtered.

Blood supply
Immune cells can enter and exit the lymph node through its dedicated blood supply.

Medulla
This central area contains antigen-presenting cells (APCs). Lymphocytes travelling through the medulla scan the APCs for information about potential infections in the body.

Nodules
Around the outside of the lymph node are nodules containing populations of antibody-producing B-cells. When activated, they divide to produce enough cells to counter an infection.



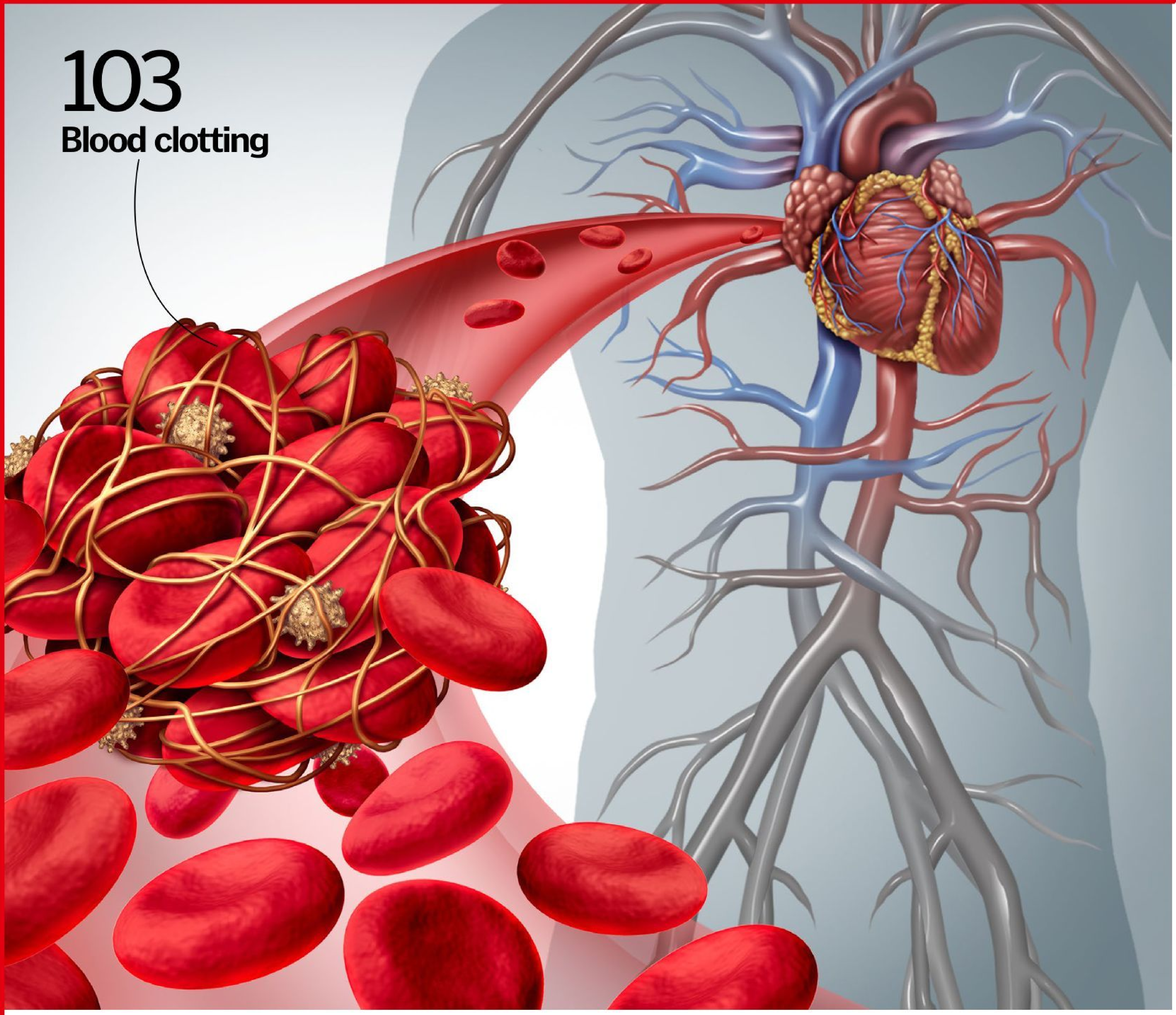
Subclavian vein
Lymph is returned to the circulatory system at blood vessels near the collarbones.

Lymphatic system
With vessels mainly in the skin, the lymphatic system (shown in green) does not follow the same course as the circulatory system.

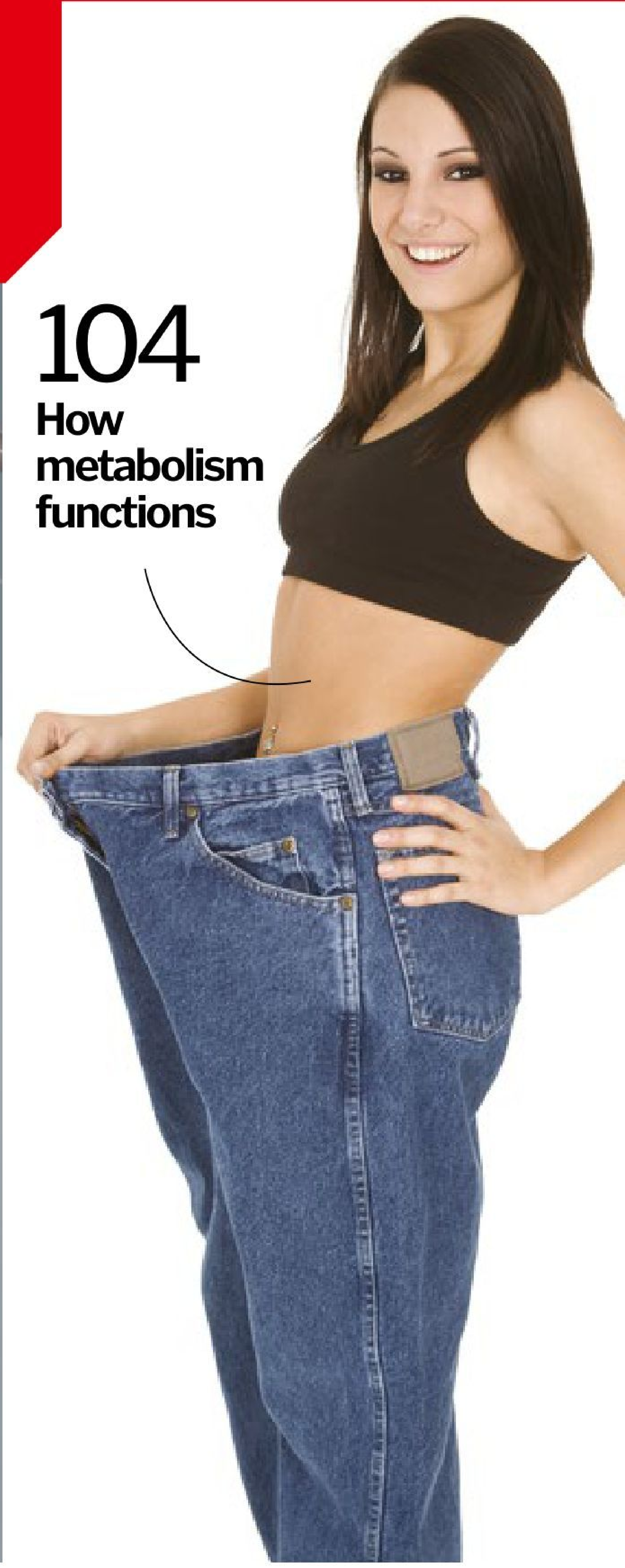
Lymph node
The lymph nodes are distributed along the lymphatic vessels. They can sometimes be felt as smooth, bean-like lumps in the neck and groin.

© SPL; Alamy; Thinkstock

HEALTH AND MEDICINE

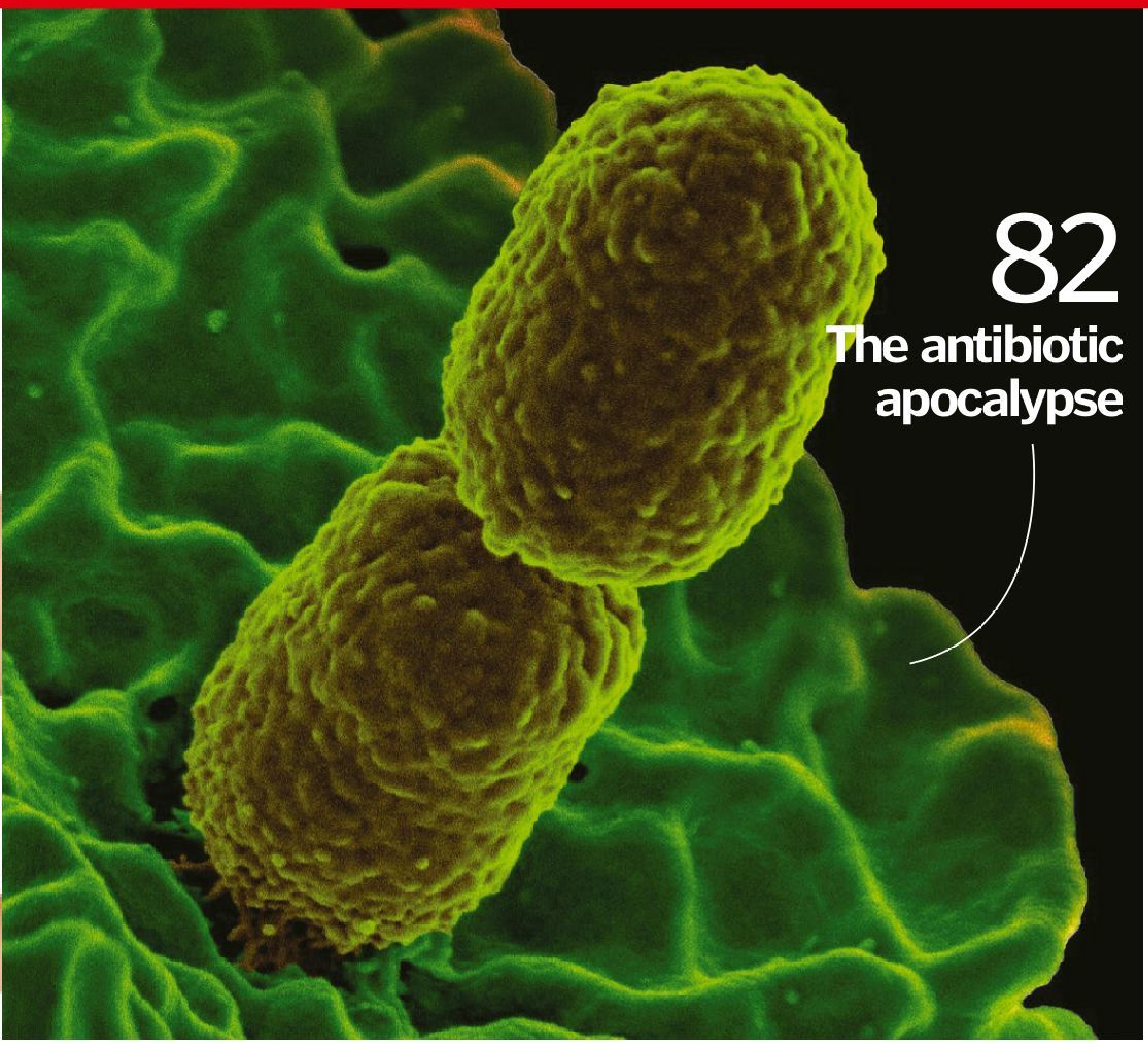


103
Blood clotting

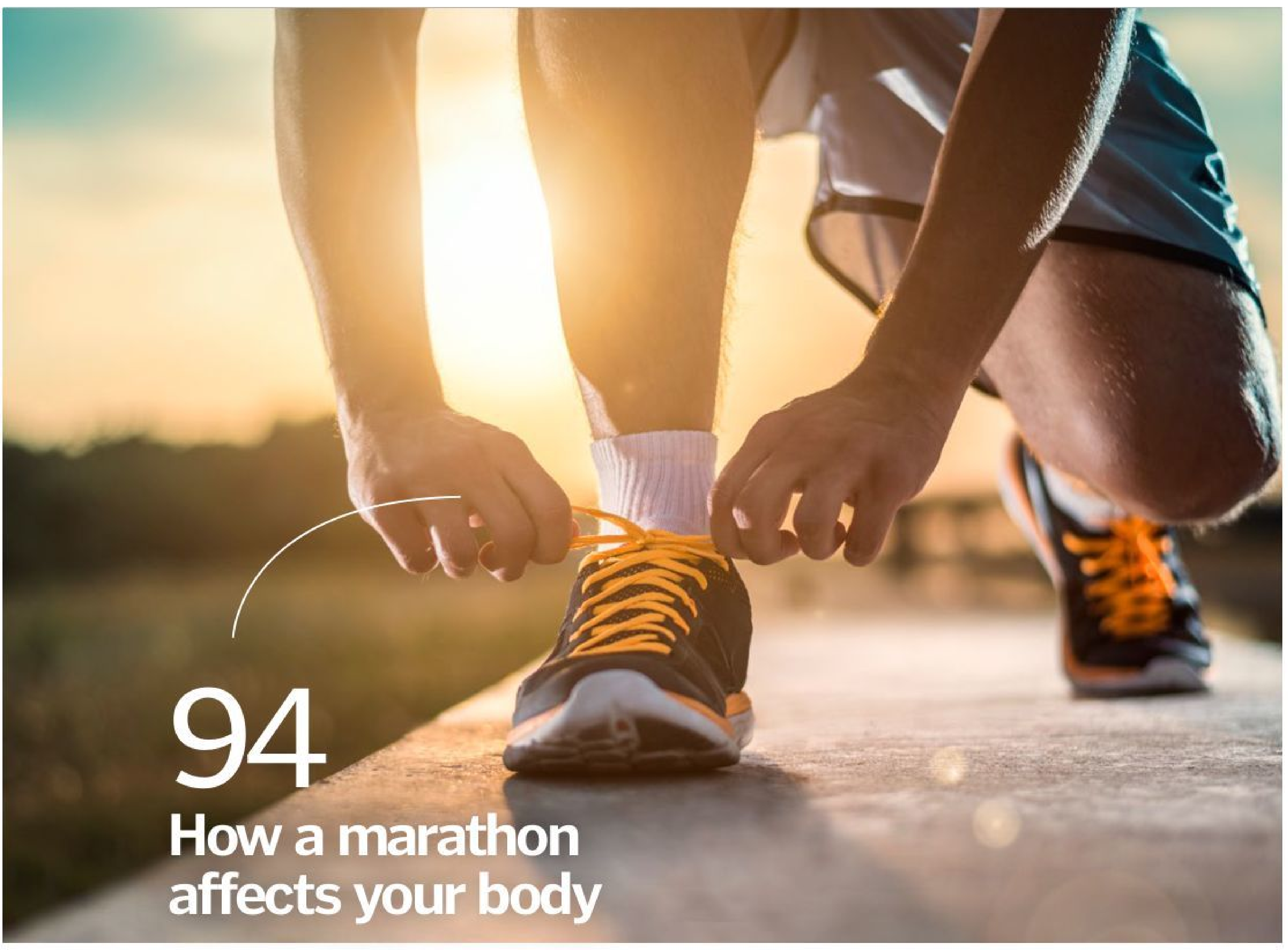


104
How metabolism functions

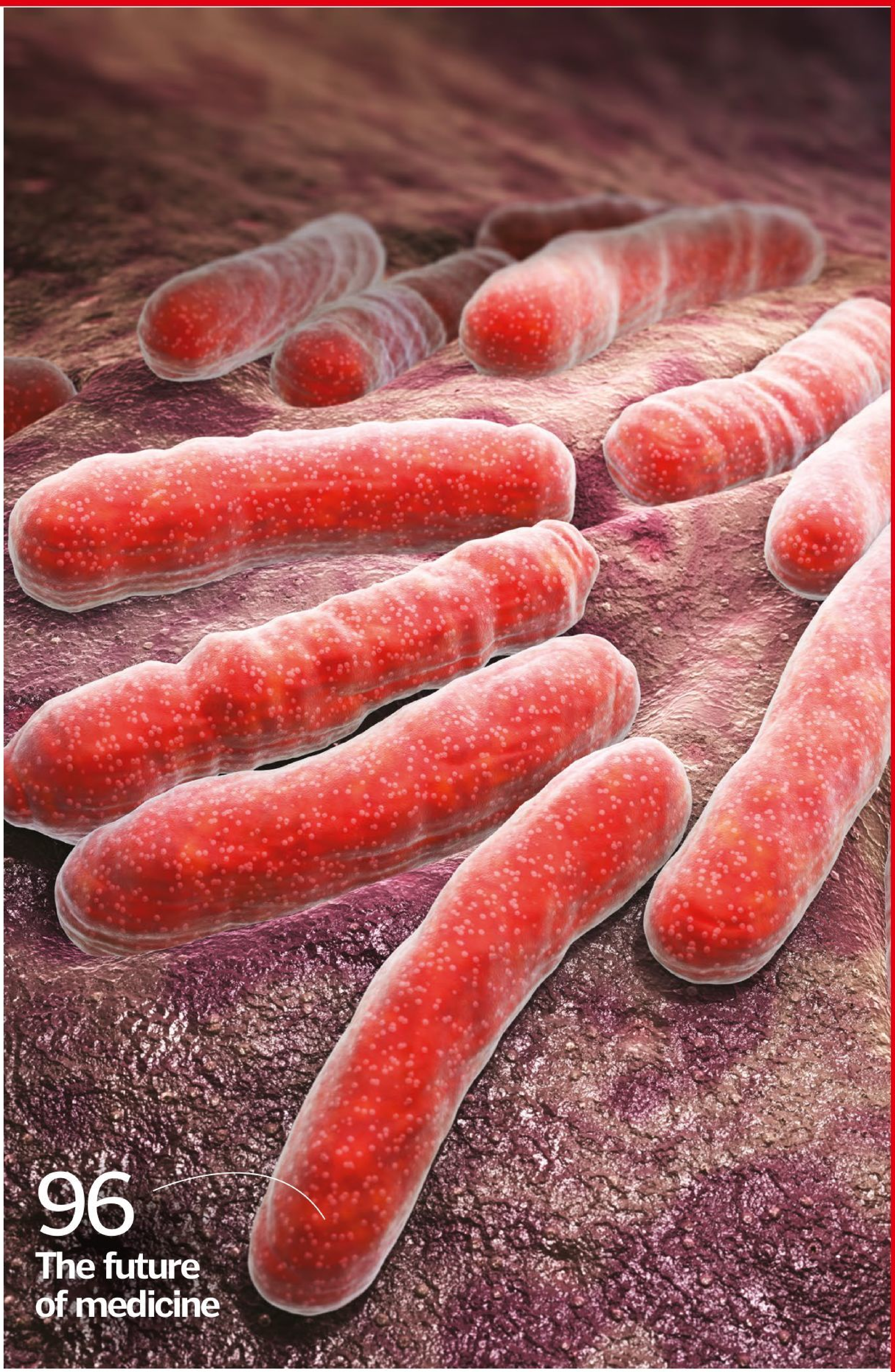
70 Outbreak
76 Anatomy of an Olympic athlete
80 The truth about hair transplants
82 The antibiotic apocalypse
84 Why do we get fat?
84 Immunisation: how it keeps you healthy
85 How do we heal?
85 Placebos – do they work?
86 Kidney transplants
88 How cloning works
92 Anaesthetics
92 Strokes
93 Rheumatoid arthritis explained
93 Why is there no cure for the common cold?
94 How a marathon affects your body
96 The future of medicine
102 Why do we get headaches?
102 Asthma
103 Cramp explained
103 Blood clotting
104 How metabolism functions
105 How does the liver detoxify?
106 How do gastric bands work?
108 How skin grafts work
108 Is cholesterol bad for you?
109 Hypermobile joints
109 What is a fit?
110 Why do we get angry?
110 What are grommets?
111 Anaphylactic shock
112 Brain surgery
116 How hyperthermic surgery works
116 What are probiotic bacteria?
117 What are tonsils for?
118 Secrets of stem cells
120 Colour blindness
120 What causes stomach ulcers?



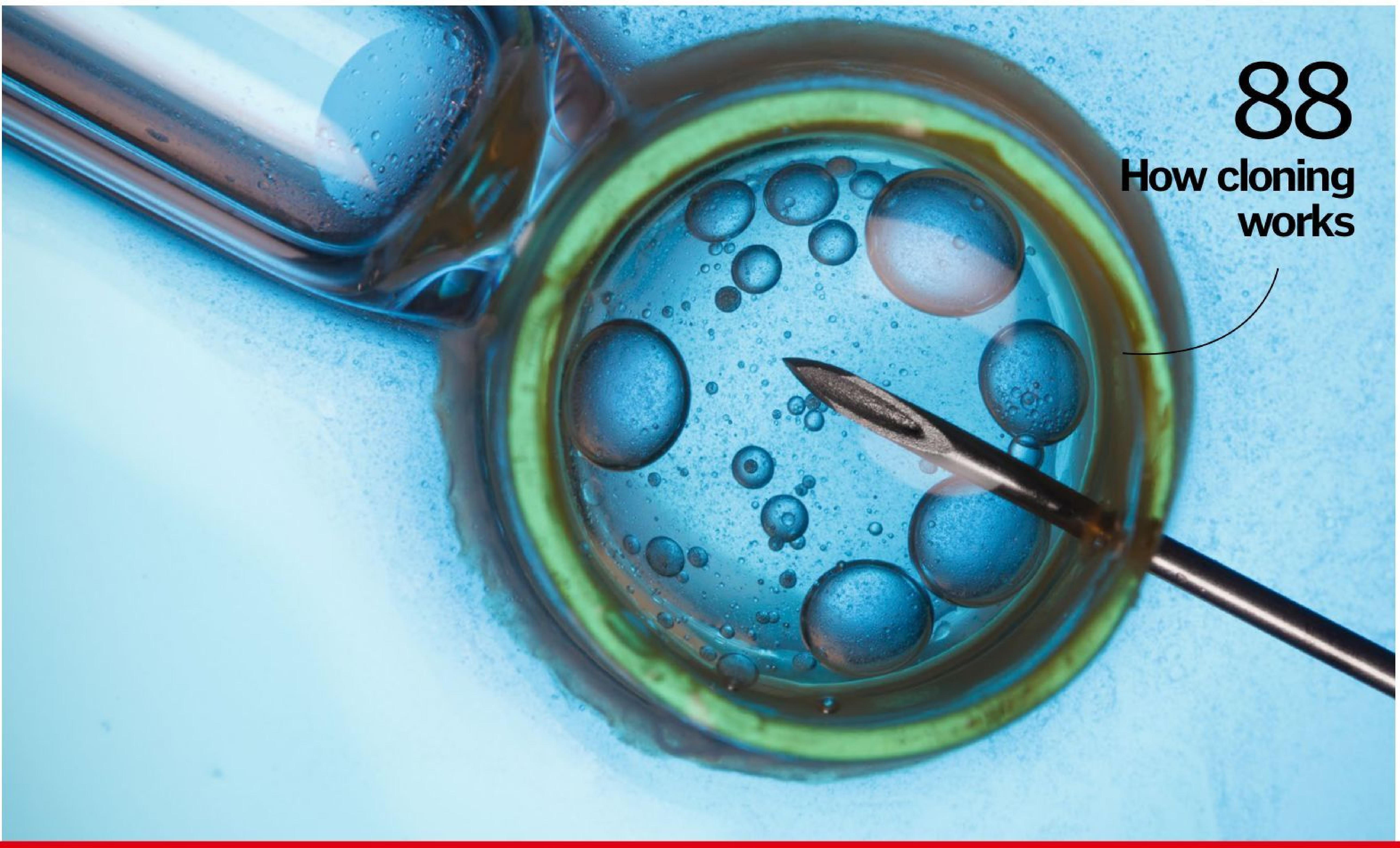
82
The antibiotic apocalypse



94
How a marathon affects your body

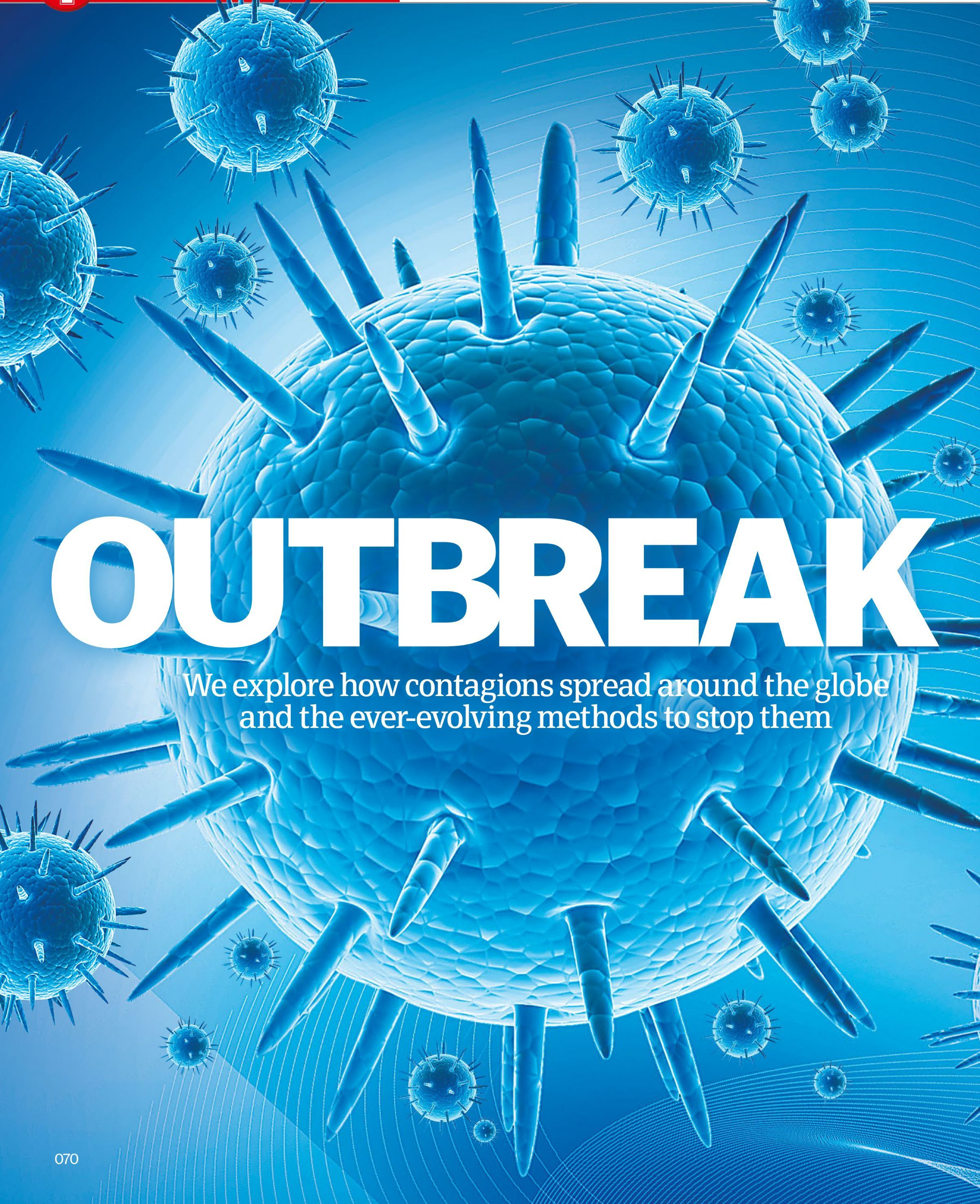


96
The future of medicine



88
How cloning works

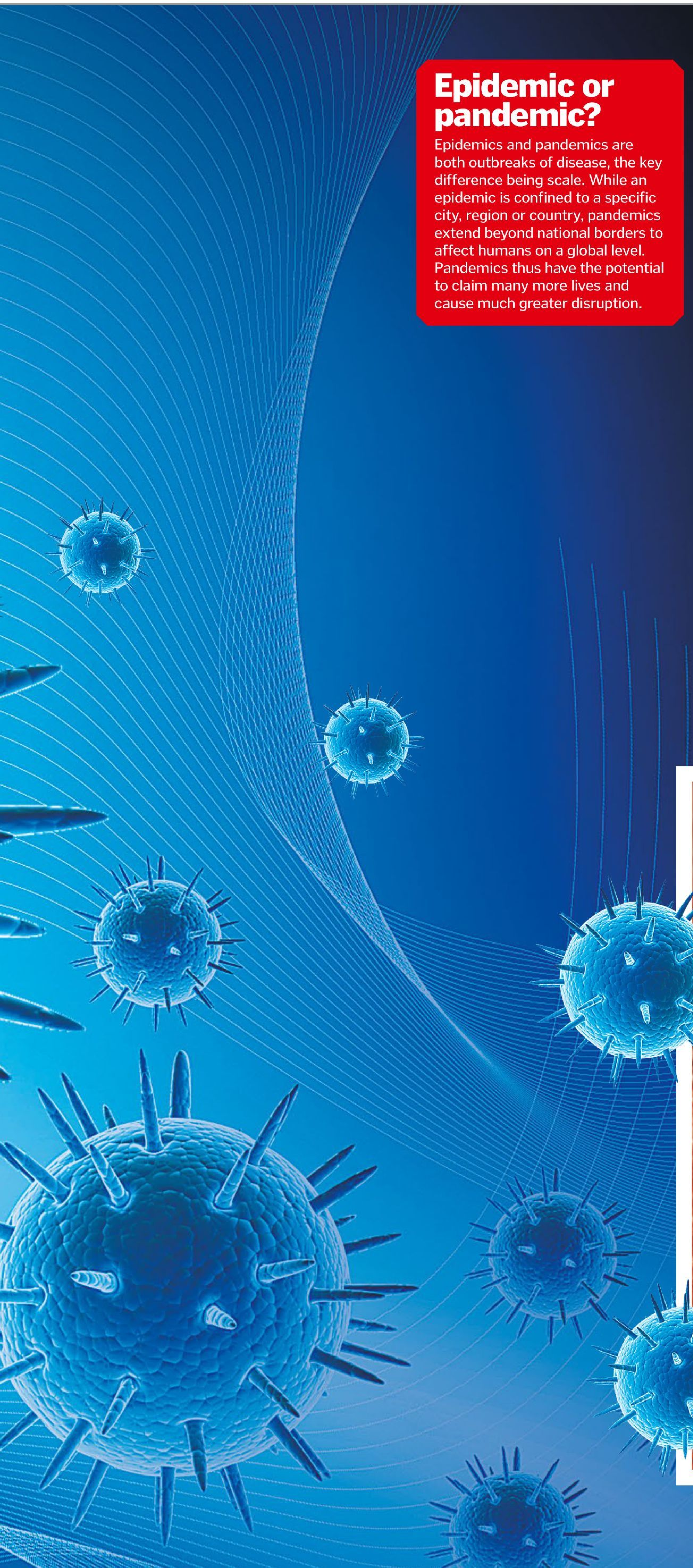
121 **Understanding chickenpox**
122 **The war against superbugs**
123 **Curing deafness**
124 **Ebola virus**
126 **How enzymes keep you alive**
126 **Bacteria explained**
127 **How to check your pulse**
127 **Keeping hydrated**
128 **Understanding diabetes**
130 **Perfect posture**
131 **How corrective lenses work**
132 **Inside laser eye surgery**



OUTBREAK

We explore how contagions spread around the globe and the ever-evolving methods to stop them

DID YOU KNOW? *Our most common gene provides no benefit to us, but some viruses use the protein it encodes to infect us*



Epidemic or pandemic?

Epidemics and pandemics are both outbreaks of disease, the key difference being scale. While an epidemic is confined to a specific city, region or country, pandemics extend beyond national borders to affect humans on a global level. Pandemics thus have the potential to claim many more lives and cause much greater disruption.

Human history is punctuated by a number of terrifying pandemics. These global outbreaks of disease will, without a doubt, remain a real threat to humanity for the foreseeable future, however our growing knowledge of medicine and how the diseases work makes us better equipped than ever to fight them.

The word 'disease' encompasses the wide range of ailments from which we can suffer. The ones that cause epidemics and pandemics are infectious diseases – those that can spread from one person to another.

Infectious diseases include everything from the common cold to HIV/AIDS. They are caused by biological agents (or pathogens) – frequently bacteria and viruses but also parasites, fungi and prions (such as bovine spongiform encephalopathy, also known as mad cow disease).

Most micro-organisms living either on or inside our bodies are totally harmless. In fact, our bodies contain up to ten times more bacterial cells than they do human cells. This still leaves a good few handfuls of pathogens intent on ensuring their survival at our expense.

Whether it's the common flu virus or more unusual bugs, these pathogens have evolved a whole arsenal of tricks to hop from one human to another, spreading through coughs and sneezes, bodily fluids and more.

Some even hitchhike on another organism that does all the legwork for them – known as a vector. Malaria is a good example of a vector-dependent disease. Caused by a parasite, malaria is carried by mosquitoes, which spread the illness between humans when they bite them. Despite these clever tactics, it's relatively rare for a pathogen to infect

The Ebola virus kills up to 90 per cent of those who contract it

© Thinkstock

enough people to spark a pandemic. One reason is that our bodies possess a highly effective defence against their onslaught: the immune system.

As we're exposed to diseases, our immune systems develop tailor-made antibodies to latch onto attackers and either neutralise them or earmark them for destruction. Over time, your body builds up a vast catalogue of antibodies. A pathogen's first attack might cause a full-blown infection, but if a repeat invasion occurs, the immune system responds swiftly to defuse the attack.

As a result (and also thanks to vaccination), a substantial proportion of the population is resistant to common diseases, making it hard for these pathogens to infect enough people at one time to cause a pandemic. Chickenpox, for instance, is highly contagious, but after a person has been attacked by it once, their body 'remembers' the intruder and the vast majority are immune to it for life.

Pandemics therefore tend to be triggered by pathogens which we have had very little exposure to and which can catch our immune systems unawares.

Historically, diseases from other countries could do just that. When European settlers arrived in North America, they introduced diseases which Native Americans had never encountered before, such as measles, influenza and smallpox. These pathogens set off waves of deadly epidemics which killed over 90 per cent of the indigenous population.

Nowadays, regular international travel spreads pathogens around, meaning 'old' diseases aren't a threat. The ones to worry about are new diseases (or variants of known diseases), which all come from one source: animals.

The animals most likely to pass on their diseases are our closest relatives, the great apes. The HIV virus, for example, has been traced back to chimpanzees in Africa who were eaten by humans in the first half of the 20th century.

Like many other zoonoses (diseases which cross the species barrier) HIV first infected a few isolated humans, but as the virus evolved it crossed another very important hurdle: it acquired the ability to transmit from one person to another. Once a disease possesses the capability to do this, it really does become a ticking time bomb.

While it's relatively easy for a pathogen to make the leap from an ape to us, or vice versa, much greater leaps are possible. Very few of us come into contact with apes, but we have a much closer relationship with domestic animals. A precursor to the influenza virus which caused the 1918 Spanish Flu is thought to have existed first in wild birds, then in domestic pigs, before jumping over to people.

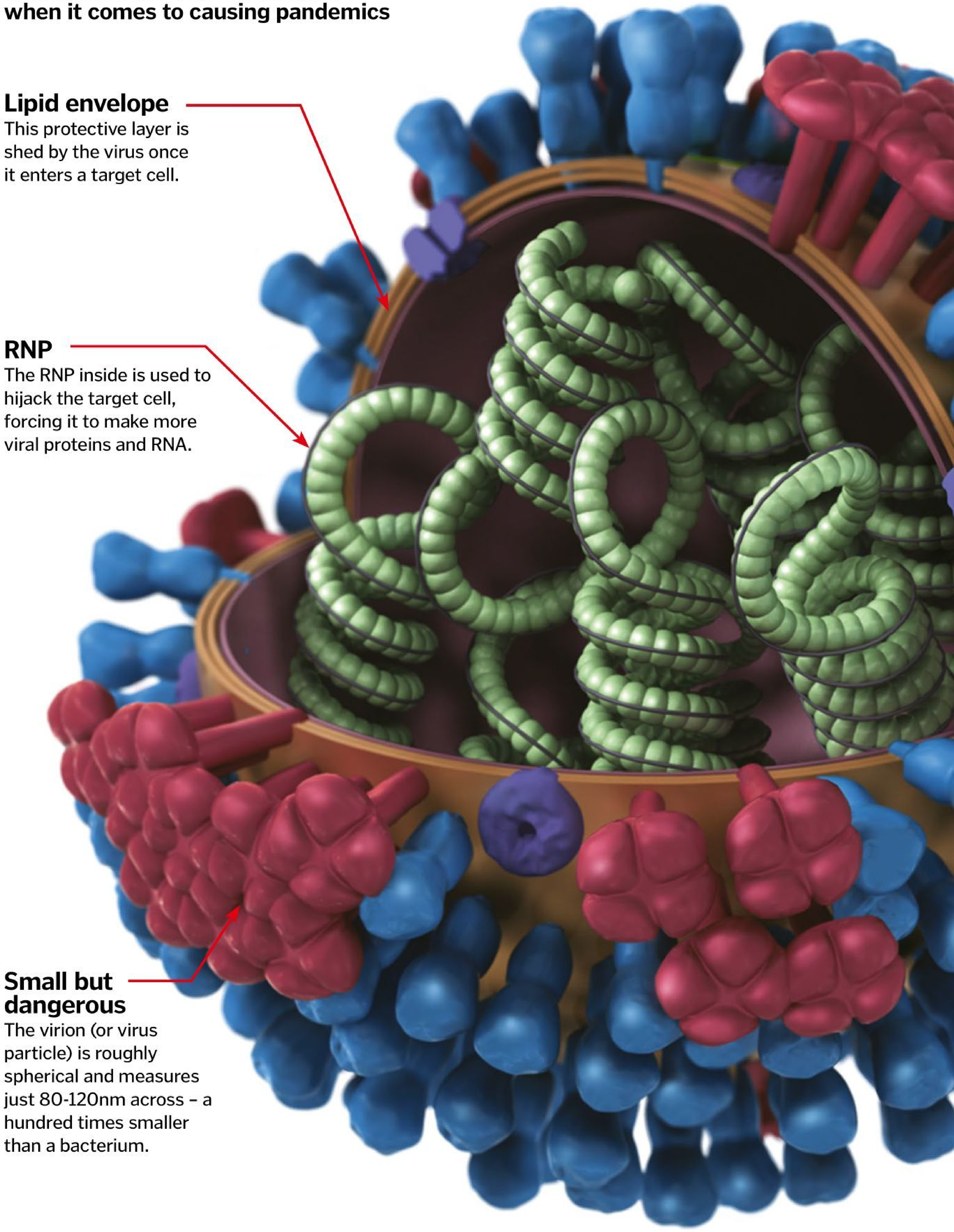
For millennia humans were entirely at the mercy of disease, but the late-18th century saw the invention of our best weapon against infection: the vaccine.

Vaccines fool the immune system into thinking it's being attacked by a pathogen, stimulating it to create an army of antibodies and killer T-cells specific to this disease. If we ever encounter the real thing, our bodies are therefore primed to fight off the infection.

To do this a tiny amount of the pathogen (usually attenuated, which means weakened) is injected into the body – this process is known as inoculation. It might come as a surprise but people were actually experimenting with inoculation in China and India as long ago as 1000 BCE.

Inside influenza

Meet the influenza virion, an expert cell hijacker and repeat offender when it comes to causing pandemics



Lipid envelope
This protective layer is shed by the virus once it enters a target cell.

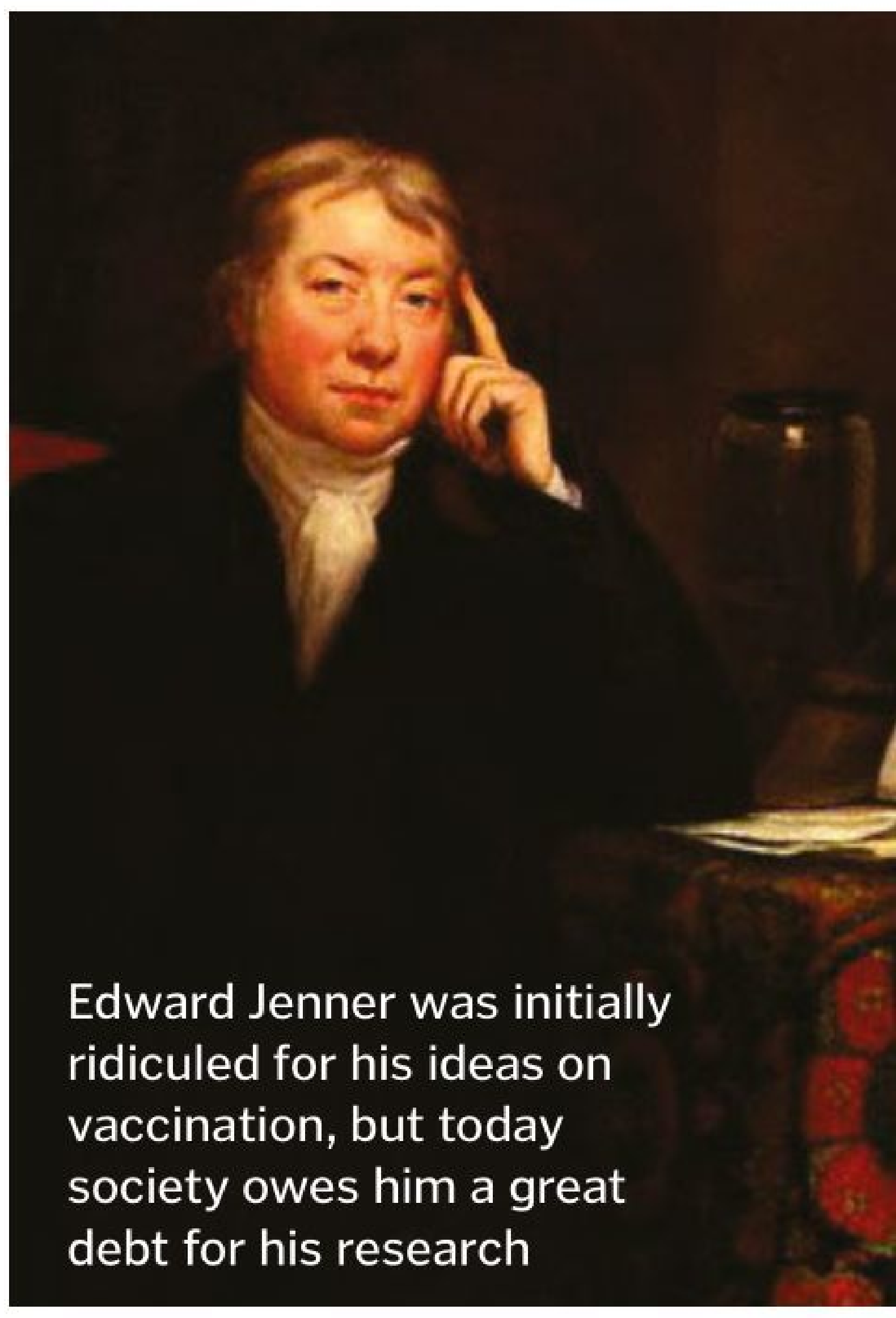
RNP
The RNP inside is used to hijack the target cell, forcing it to make more viral proteins and RNA.

Small but dangerous
The virion (or virus particle) is roughly spherical and measures just 80-120nm across – a hundred times smaller than a bacterium.

However, it wasn't until 1796 that the first successful vaccination was produced.

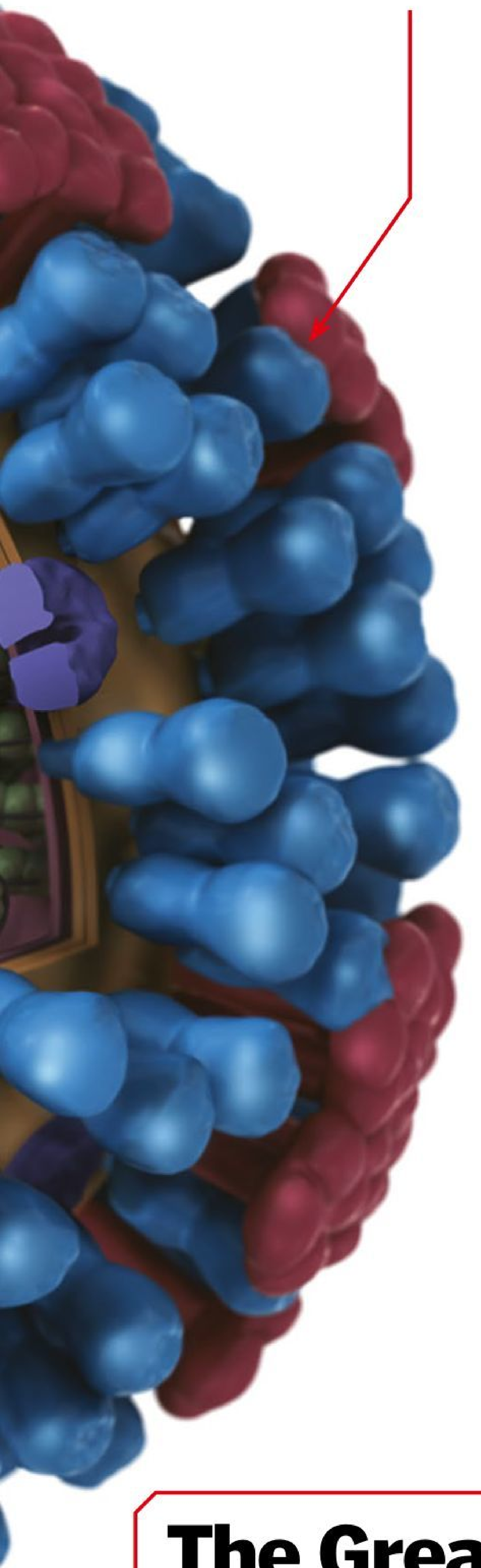
Throughout the 18th century, smallpox was a leading cause of death around the world. English physician Edward Jenner noticed that milkmaids who had caught an illness called cowpox seemed to be immune to smallpox. By injecting patients with pus taken from cowpox sores, he was able to confirm his hypothesis and the first vaccine was born. Vaccination was adopted across the globe and smallpox was officially eradicated in 1979.

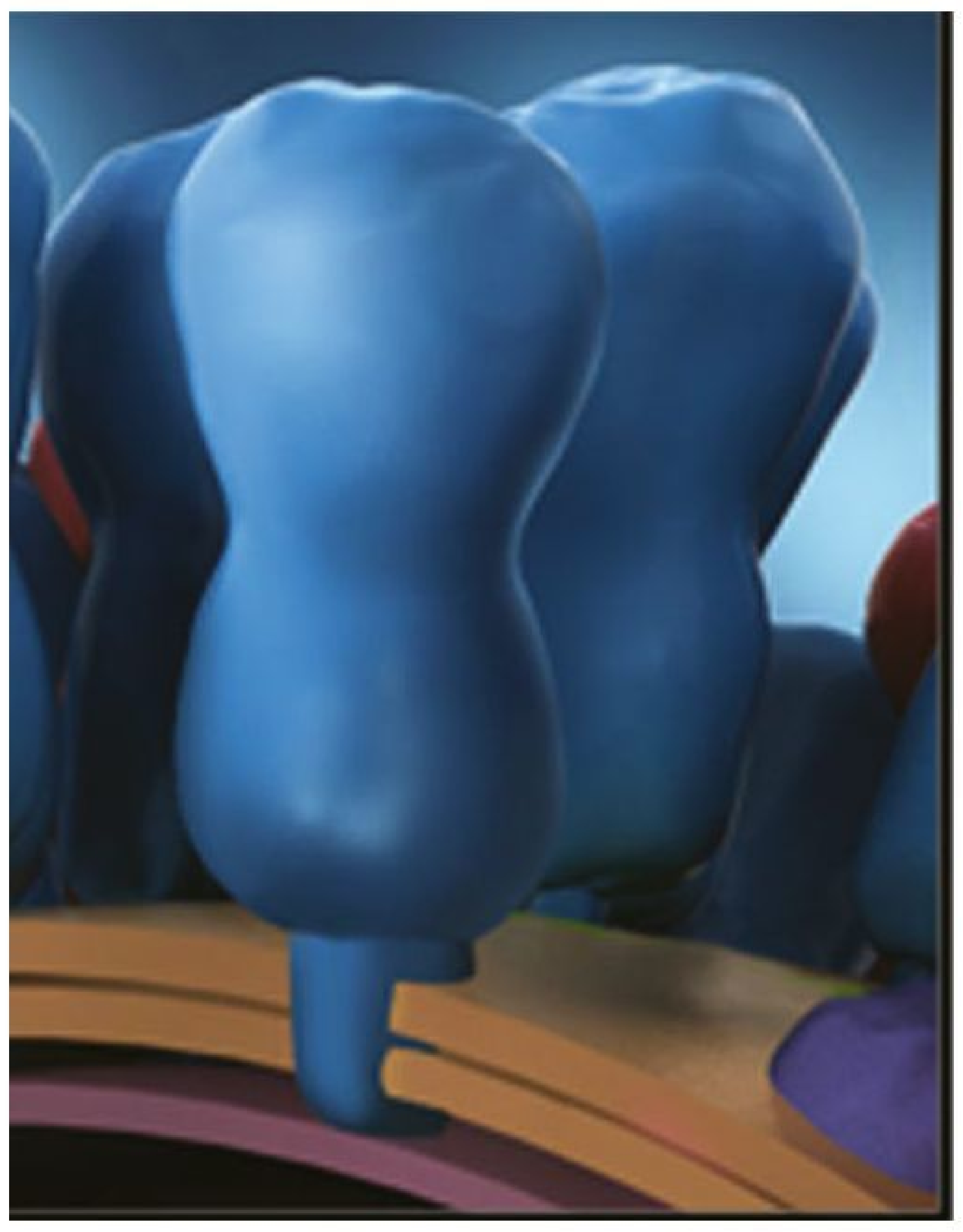
Jenner's landmark work with smallpox paved the way for a wide variety of vaccines to be created. In the late-19th century, microbiology pioneer Louis Pasteur developed vaccines against anthrax and rabies. A key innovation was that Pasteur's method consisted of treating pathogens to render them totally harmless.



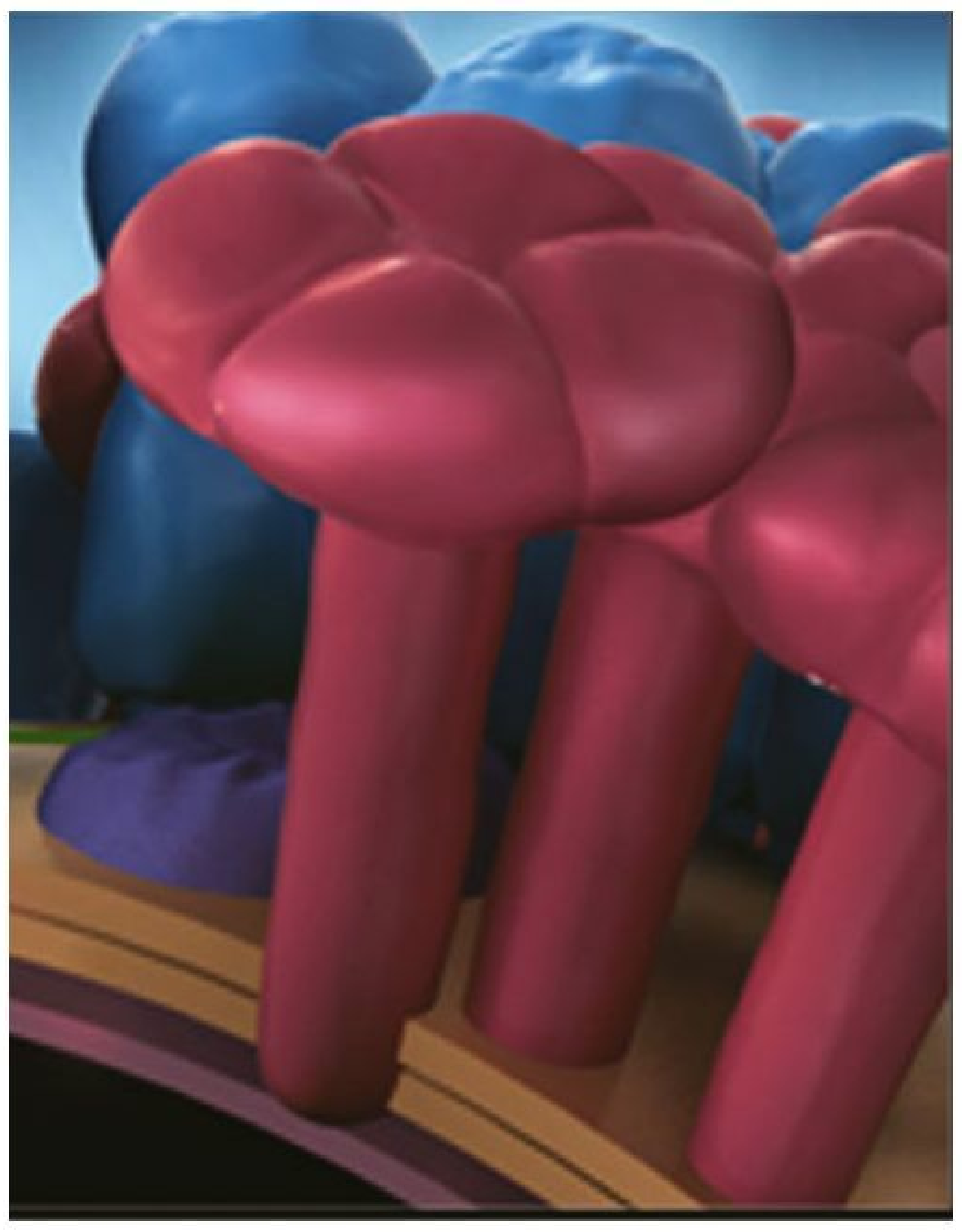
Edward Jenner was initially ridiculed for his ideas on vaccination, but today society owes him a great debt for his research

Surface proteins
Haemagglutinin and neuraminidase are vital to the virion's function, making them great targets for antibodies and antiviral drugs.

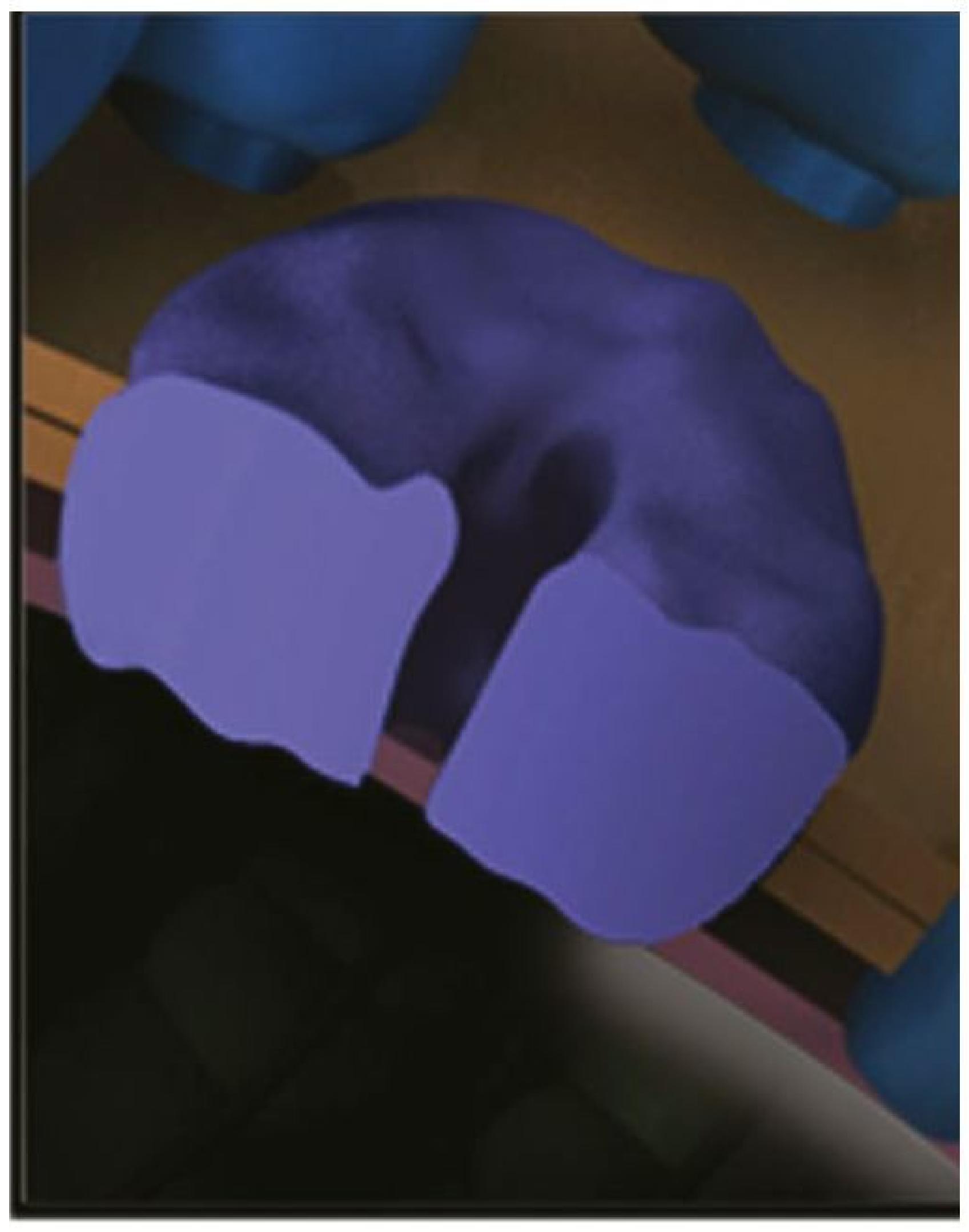




Haemagglutinin
This spike-shaped protein is one of the flu's key weapons, helping the virion stick to a target cell to begin its attack.

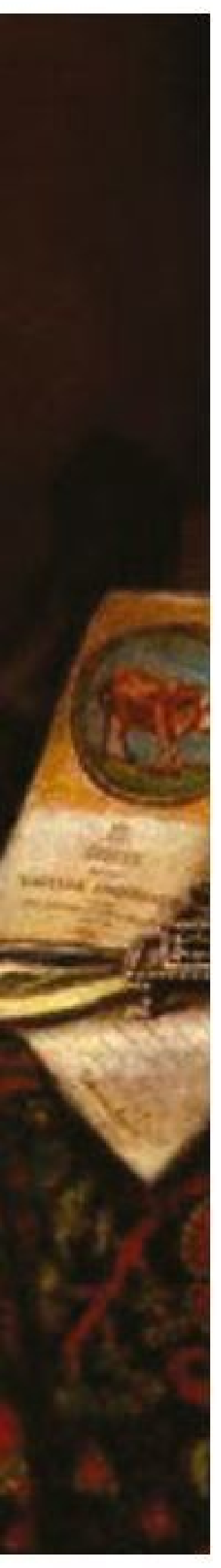


Neuraminidase
Once its job is done, the neuraminidase enzyme clips polysaccharide chains allowing the virion to leave the cell.



M2 ion channel
The M2 protein lets hydrogen pass into the virion, increasing its acidity and exposing its RNA.

Ribonucleoprotein
The virion's genetic code consists of six to eight segments of RNA, encased in a protein sheath (making up the RNP).



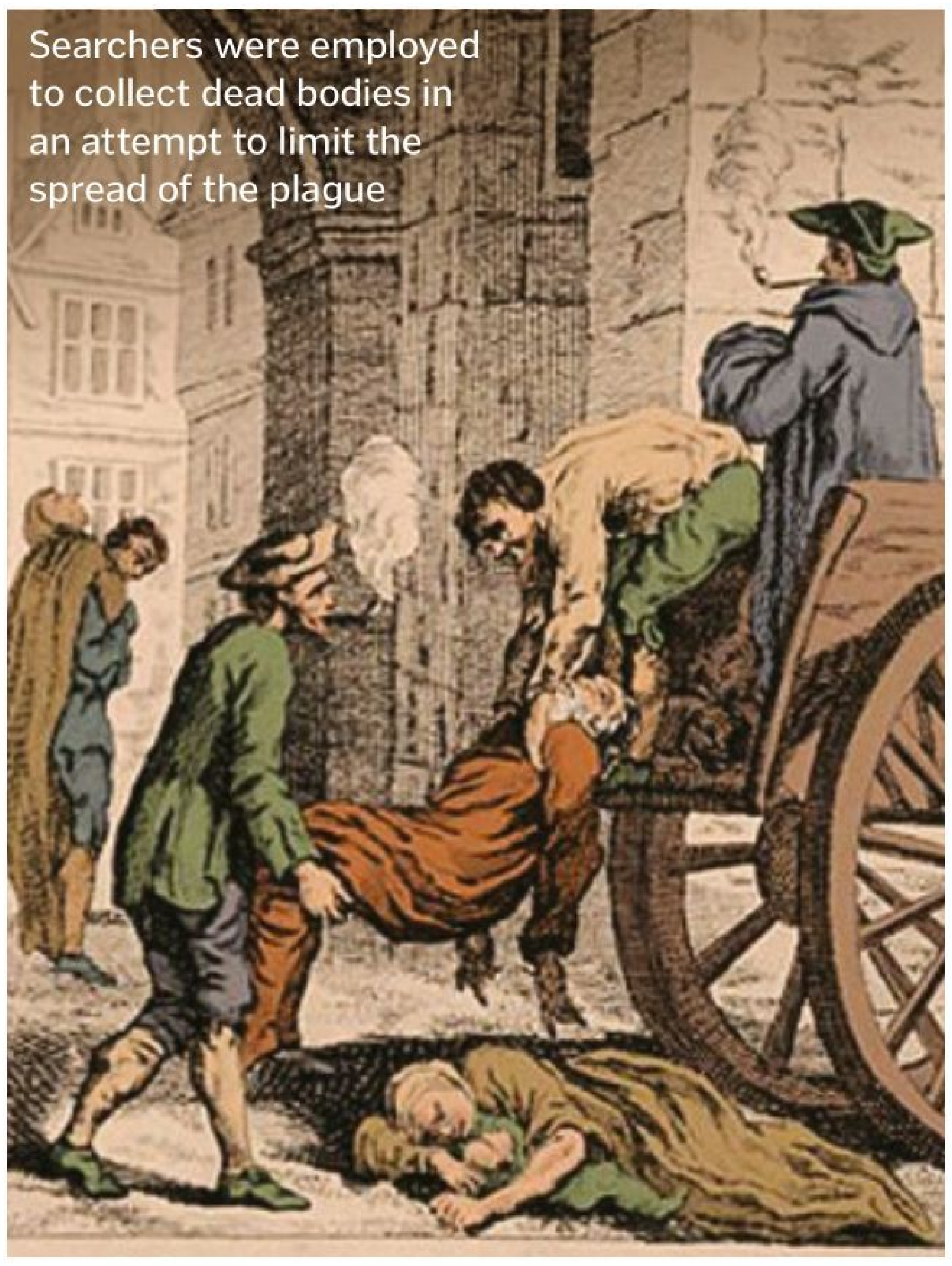
The Great Plague

Probably the deadliest pandemic in human history, the Great Plague, or Black Death, ravaged Europe from 1348-1350, killing up to half of the population in that short time. At its root was the bubonic plague-causing Yersinia pestis bacterium.

Originating in Asia, the plague first struck in China where it killed approximately 25 million people. It then spread into Europe following the Silk Road. Y pestis bacteria were carried by fleas, who themselves hitchhiked on the rats that thrived in the hulls of merchant ships.

After first landing on the shores of Italy in 1347, the Black Death had swept as far north as England by the following summer and continued onward to Germany and Scandinavia in 1348.

Highly infectious, the disease struck and killed its victims with startling speed. The telltale sign of infection was the appearance of swollen lymph glands – called buboes – typically around the groin, neck and armpits. Sufferers then developed a high fever and began to vomit blood, usually dying within a week of the first symptoms showing. With no effective cure to keep it in check, the plague returned repeatedly for the next 300 years.



Searchers were employed to collect dead bodies in an attempt to limit the spread of the plague

Interview
How to tackle pandemics

London School of Hygiene and Tropical Medicine's Prof John Edmunds explains all

What disease do you think will cause the next pandemic?

John Edmunds: Flu! Well, I don't know if it will cause the *next* one, but it will definitely cause a pandemic in the future. As for other diseases, it's hard to predict. There are various surveillance efforts underway to see which pathogens are circulating among animals to gain some understanding of what the most likely pandemics will be. It's still a huge guess frankly, but it's worth keeping track of these diseases and characterising them because, if they do start spreading in humans, we need to know about them.

How is our track record for detecting and dealing with pandemics?

JE: We're very good at responding to these things now. There's a lot of fuss about the 2009 flu pandemic, but that virus was sequenced from top to tail in a matter of days after the first cases were isolated. We knew an awful lot about it very quickly. The same goes for the SARS virus.

Could a pandemic end humanity?

JE: I suppose it could. But do I think it will? No. Medical and allied sciences like epidemiology and modelling are so strong now. But there's a significant risk to certain populations – especially the countries that don't have the facilities to respond. Take SARS – we got on top of it just in time. The countries that it initially spread to had well-functioning health systems. But there are other countries that aren't in that category, like India or Indonesia. What if it had jumped from there to Africa? Would we have been able to stop it spreading in those settings? It would have been incredibly difficult. So I think it's unlikely a pandemic would wipe out humanity, but it could cause huge damage, particularly in some areas of the world with weak health infrastructure.

For more about Professor Edmunds' work, visit the flu outbreak monitoring site: http://flusurvey.org.uk.

© Alamy; CDC

In the following century, new vaccines were developed at an astonishing rate. American microbiologist Maurice Hilleman alone led the invention of over 30 vaccines (including those against measles, mumps, hepatitis A, hepatitis B and meningitis). Widespread vaccination for common pathogens means that most of the population is now resistant to them, preventing epidemics and forever changing our relationship with diseases which plagued humanity for centuries or even millennia.

But while it is easy to create vaccines against some diseases, others are far more elusive due to the rapid changes they undergo. The most notorious of these shape-shifters is the HIV virus. HIV has one of the highest mutation rates known, reshuffling its genes constantly to change the shape of its surface proteins. By modifying its disguise, it makes itself unrecognisable to antibodies, dodging the immune system's guardsmen. Developing a vaccine against HIV is therefore a tremendous challenge. HIV also attacks the immune system directly.

Other diseases, such as influenza, are relatively easy to vaccinate against once a new strain has been identified, however the unpredictability of outbreaks means that they are still a real threat. Influenza exists principally in wild birds, but every so often a new strain of the virus will become transmissible between humans, sparking epidemics and even pandemics, such as the HN51 virus. The time and location of these spillovers are virtually impossible to predict, though monitoring wild birds is one way of keeping an eye out for new strains of the virus which have the potential to make the leap.

In a number of ways, modern society leaves us more exposed to pandemics than we were in the past. For one thing, nowadays about 50 per cent of us live in cities where we come into contact with a huge number of people on a daily basis, facilitating the spread of disease.

The ever-growing number of international flights also accelerates transmission, allowing pathogens to hop from one continent to another in a matter of hours. In 2003, SARS (severe acute respiratory syndrome) spread to 29 countries across three continents in just a few months.

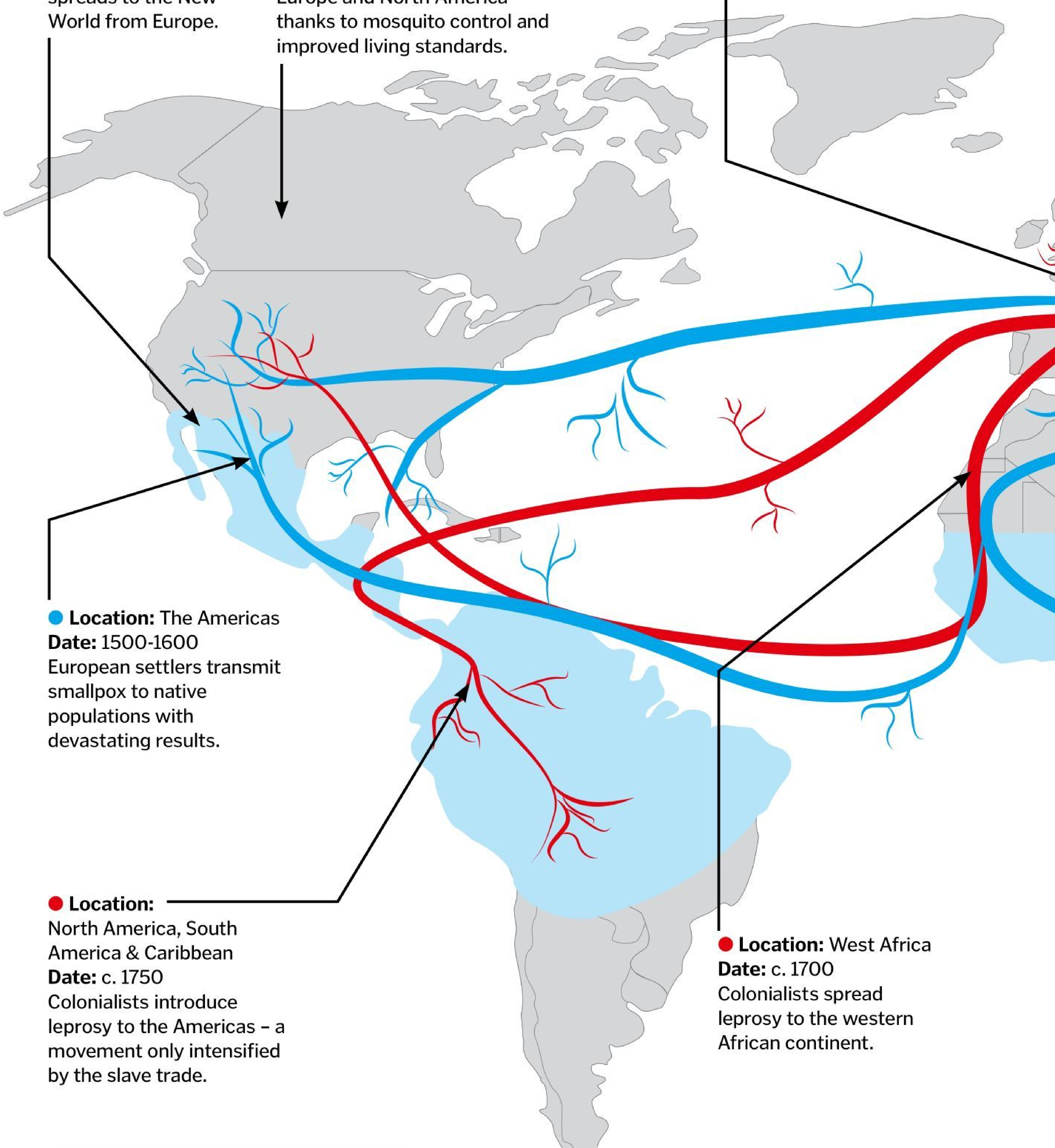
Despite this, our understanding of pathogens is continually improving. SARS was a brand-new disease, but the global medical community rapidly got to know its idiosyncrasies and brought it under control. While we don't have a vaccine for HIV yet, treatments have improved dramatically, and public health measures have helped to reduce or stabilise infection rates in most countries.

Pandemics will inevitably continue to strike in years to come, but we can rest assured that we are better armed than ever in our eternal battle against pathogens.

How pandemics go global

Track how three of the most common diseases spread around the world...

■ Smallpox ■ Leprosy ■ Malaria



● **Location:** Americas
Date: c. 1600
Following a familiar pattern, malaria spreads to the New World from Europe.

● **Location:**
North America & Europe
Date: 1950s
Malaria largely disappears from Europe and North America thanks to mosquito control and improved living standards.

● **Location:** Europe
Date: c. 327 BCE
Alexander the Great's army returns from India, bringing leprosy to Europe.

● **Location:** The Americas
Date: 1500-1600
European settlers transmit smallpox to native populations with devastating results.

● **Location:**
North America, South America & Caribbean
Date: c. 1750
Colonialists introduce leprosy to the Americas – a movement only intensified by the slave trade.

● **Location:** West Africa
Date: c. 1700
Colonialists spread leprosy to the western African continent.

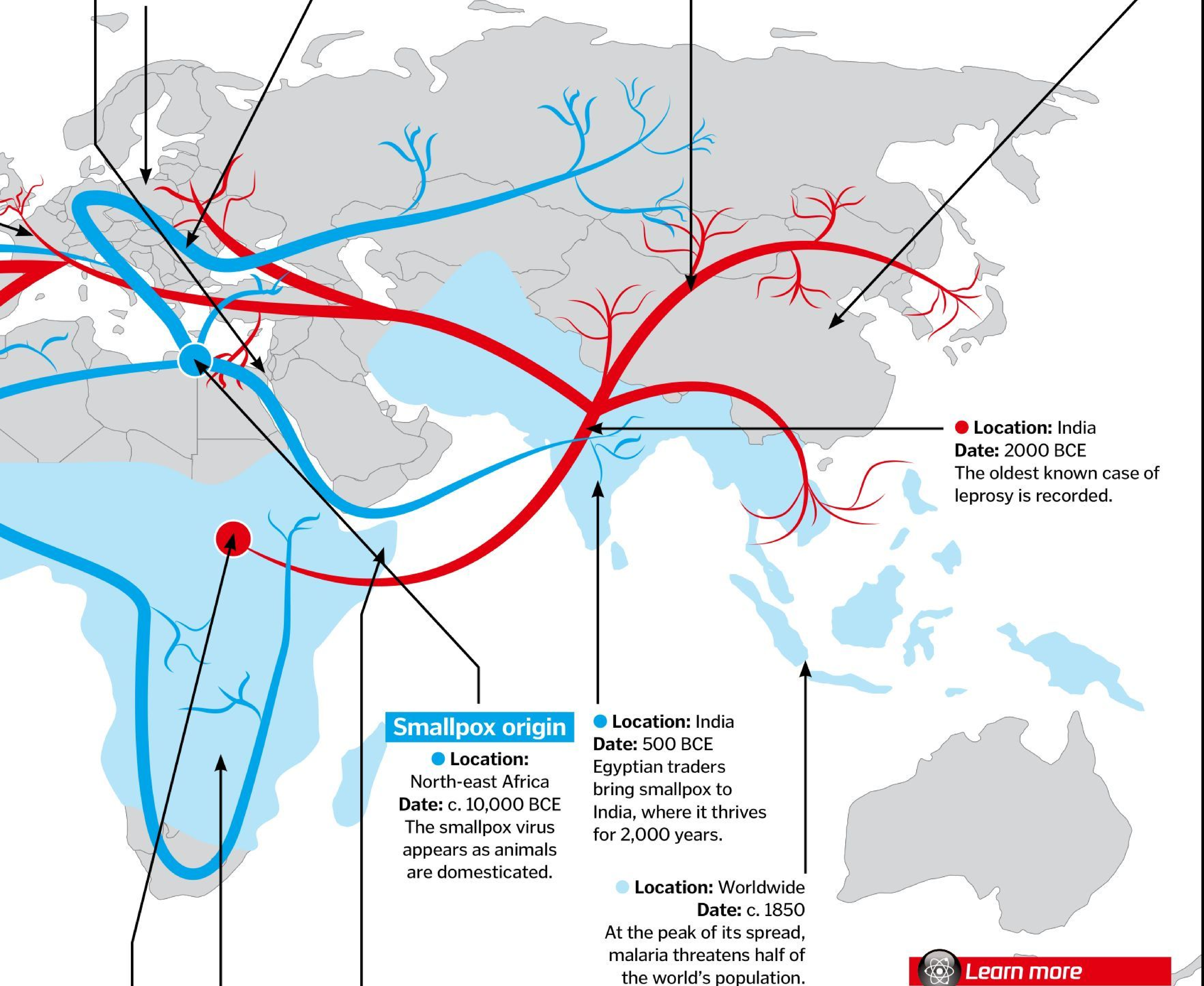
Smallpox

Following the discovery of a vaccine this acute and often-fatal contagious disease has now been eradicated. Smallpox develops in those exposed to the Variola virus. Following exposure the virus incubates for a period of usually 12-14 days during which time the individual is not contagious. After incubation, however, the sufferer will experience feverishness, sickness and headaches before developing the dreaded rash. This is when the victim is at their most contagious. The itchy red spots become fluid-filled pustules that scab over. The victim will remain contagious till all the scabs fall off.

Leprosy

Though an ancient illness, leprosy – or Hansen's disease – remains a highly infectious, chronic ailment today. This isolating disease is caused by a microbacterium in the environment – probably in the form of nasal mucus droplets – which is absorbed into its victim's bloodstream. Leprosy affects the skin and nerves, causing lesions and patches on the skin as well as loss of sensation and weakness in the hands, feet and face. While historically people believed that the disease caused parts of its sufferers to 'fall off' it is in fact the numbness caused by nerve damage that leads leprosy sufferers to injure themselves. For example, they could burn themselves on a flame and not even feel it. Today the disease is curable with the help of antibiotics.

DID YOU KNOW? *The World Health Organisation uses a six-stage scale to classify the severity of an influenza pandemic*



● **Location:** Egypt
Date: 1145 BCE
Earliest evidence of smallpox DNA found in mummies.

● **Location:** Europe
Date: c. 1500
Malaria extends its reach into northern Europe as trade intensifies.

● **Location:** Europe
Date: c. 1500
Smallpox becomes established, possibly as a result of increased travel during the Crusades.

● **Location:** China
Date: c. 250 BCE
First documented cases of leprosy in China, probably spread by traders.

● **Location:** China
Date: 2600 BCE
Earliest written report of malaria in China.

● **Location:** India
Date: 2000 BCE
The oldest known case of leprosy is recorded.

Smallpox origin
● **Location:** North-east Africa
Date: c. 10,000 BCE
The smallpox virus appears as animals are domesticated.

● **Location:** India
Date: 500 BCE
Egyptian traders bring smallpox to India, where it thrives for 2,000 years.

● **Location:** Worldwide
Date: c. 1850
At the peak of its spread, malaria threatens half of the world's population.

Malaria origin
● **Location:** Africa
Date: 10,000 BCE
Like modern man, malaria emerges in Africa and follows humans migrating into Eurasia.

● **Location:** Somalia
Date: 1977
Last reported case of naturally contracted smallpox.

Leprosy origin
● **Location:** East Africa
Date: c. 40,000 BCE
Leprosy bacterium believed to originate in eastern Africa or the Middle East.

Learn more

From informative timelines to fascinating articles, find a mine of information on diseases and the development of the vaccine at **www.historyofvaccines.org** – an online resource that was put together by the College of Physicians of Philadelphia.

Malaria

Though malaria is not contagious (ie not passed from person to person like a cold) this disease endemic to the tropics is a widespread killer. It's transmitted by the presence of a certain single-celled parasite in the saliva of female mosquitoes. When the mosquito pierces the skin of her victim with a straw-like proboscis mouthpart to obtain blood, she also releases some saliva which acts as an anticoagulant to keep the blood flowing. In doing so she also passes deadly parasites into the victim's bloodstream. Flu-like symptoms usually occur between ten days and four weeks after infection, however the parasite can lie dormant in the liver for up to four years before making the victim sick.

Pulling the plug on a pandemic

1 Vaccination

By far the most effective means of stopping disease in its tracks, however new vaccines can take six months or more to develop.

2 Education

Whether they advocate hand washing, face masks or condoms, public education efforts can dramatically cut down infection rates.

3 Reducing travel

Grounding flights and encouraging authorities to limit all forms of travel can help to put the brakes on a potential pandemic.

4 Limiting contact

Encouraging companies to call off meetings and asking people to stay at home limits exposure to pathogens.

5 Pre-outbreak monitoring

By keeping a close eye on animal diseases which could one day infect humans, scientists get to know potential future enemies.

© Thinkstock

ANATOMY OF AN OLYMPIC ATHLETE

How do these real-life superhumans differ from your average Joe?

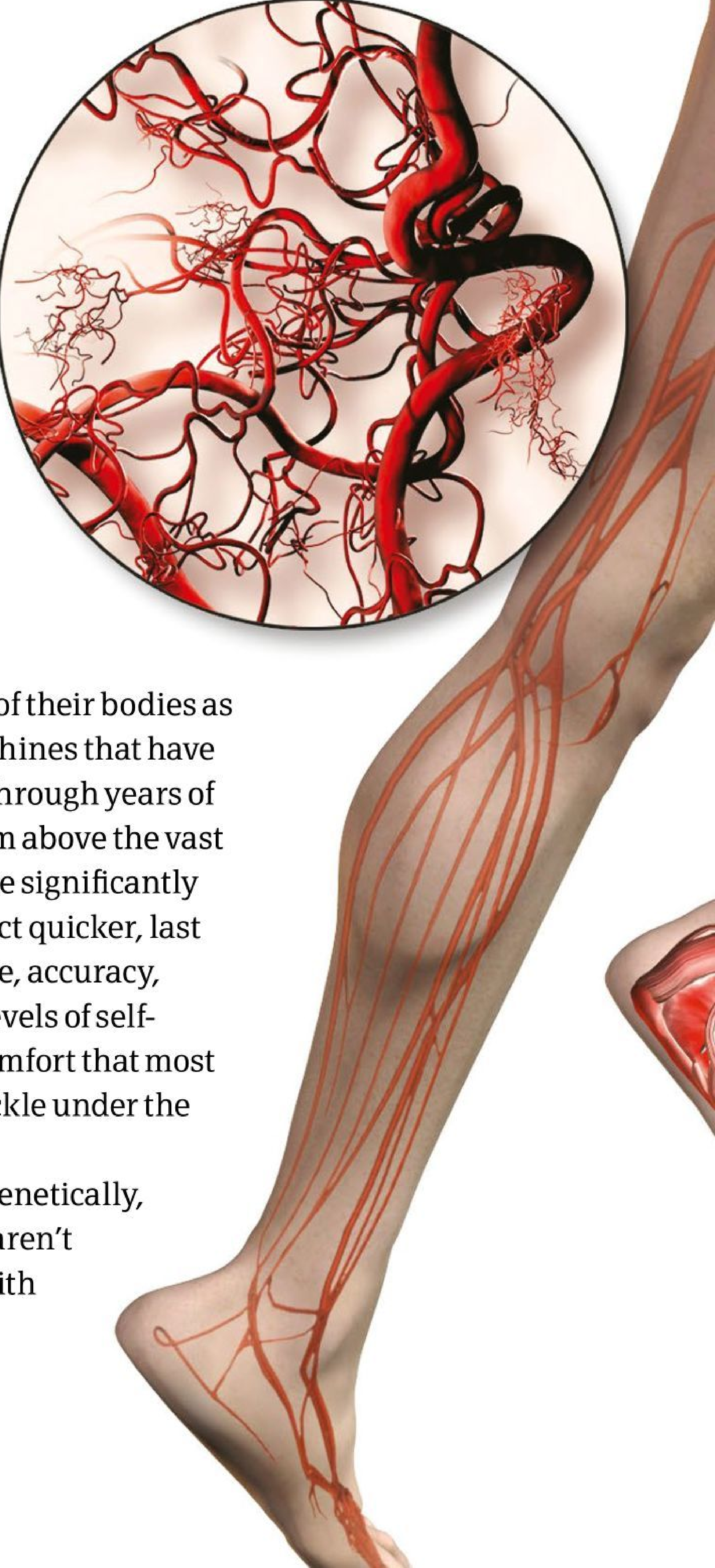
When we talk about superhumans, shooting lasers and turning invisible aside, there's a process of comparable feats that we normally run through. So, for example, the average guy might be able to sprint at 29 kilometres (18 miles) per hour but Superman can travel faster than a speeding bullet (roughly 1,300 kilometres/800 miles per hour).

Similarly, a strong person might be able to lug a 70-kilogram (150-pound) canister around a pub, but in comparison The Thing could tow a 14,000-kilogram (31,000-pound) double-decker bus.

These are feats of fantasy, but we don't have to look to the world of fiction for truly astonishing human physical acts. In fact, a lot of sports people capable of testing the boundaries of the biological machine that is the human body will currently be busy preparing for the Tokyo Olympics in 2020.

So what is it exactly that's stopping any of us from stepping up to the starting line and providing a serious challenge to Usain Bolt or the next great sprinter for the 100-metre gold medal? The answer might seem obvious, but even though we're made of the same fundamental building blocks, Olympians are built very differently. Think of their bodies as highly specialised machines that have upgraded themselves through years of training, elevating them above the vast majority of us to become significantly faster and stronger, react quicker, last longer, improve balance, accuracy, dexterity and endure levels of self-inflicted physical discomfort that most of us would quickly buckle under the stress of.

It seems unfair but, genetically, many, if not most of us aren't even on an even keel with Olympians when we're born, as many athletes



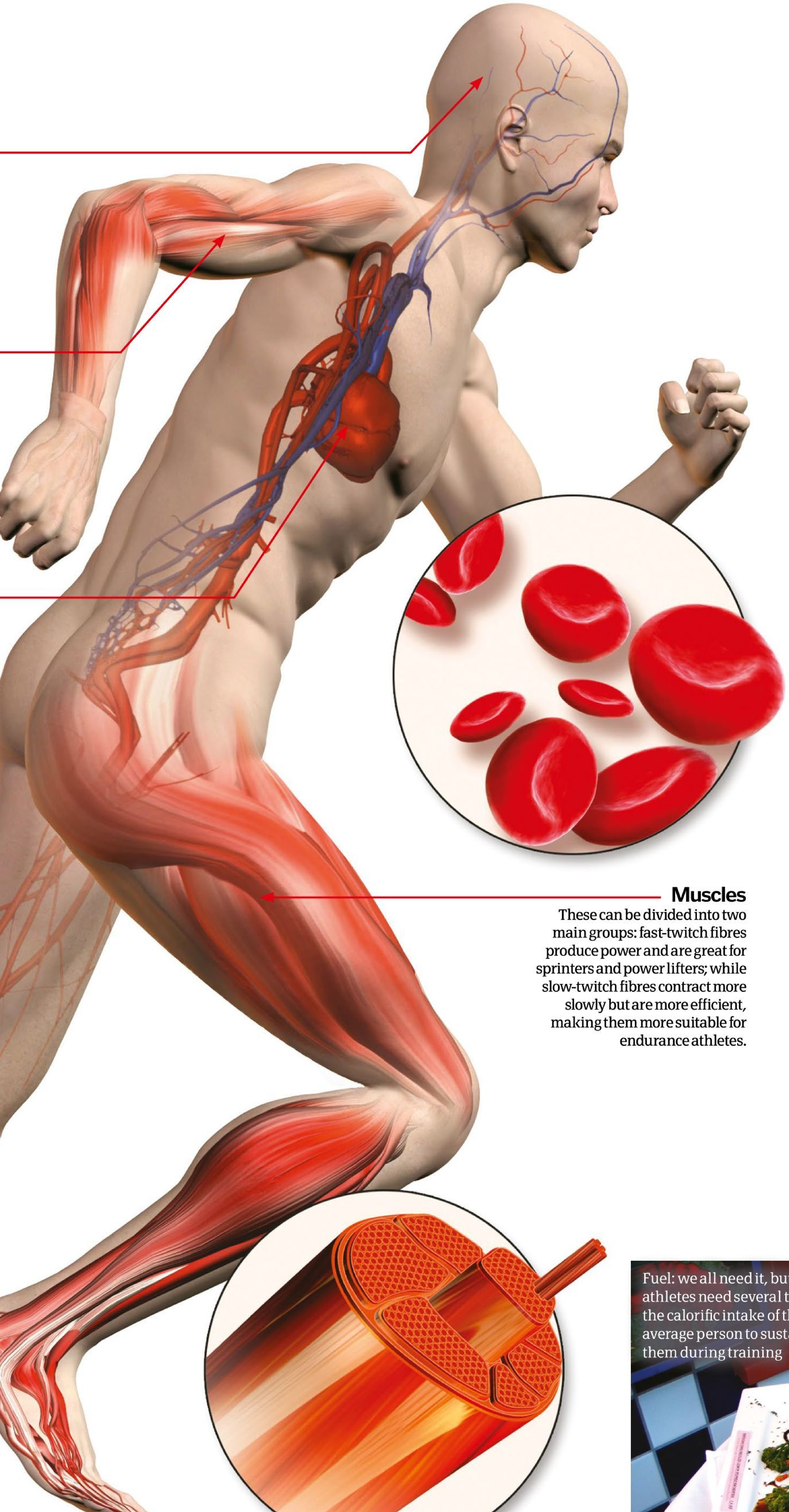
Olympian anatomy

Brain
Whether a runner is sprinting 100 metres (328 feet) or a pentathlete is guiding their horse, with years of training the brain of an Olympian changes and grows in harmony with other physical developments.

Skeleton
As a part of any physical training, bones strengthen with the stresses that muscles place upon them. Caucasians tend to have light bones while Polynesians naturally have a higher bone density, which can be genetically advantageous for certain sports.

Cardiovascular system
A strong heart and big lungs mean an athlete can last a long time in any event. A high red blood cell count will increase oxygen delivered to the muscles and a good circulation means oxygen will get where it's most required.

DID YOU KNOW? *In 1968, Hans-Gunnar Liljenwall became the first person to be tested positive for a banned substance: alcohol*



Muscles

These can be divided into two main groups: fast-twitch fibres produce power and are great for sprinters and power lifters; while slow-twitch fibres contract more slowly but are more efficient, making them more suitable for endurance athletes.

An Olympian versus you!

Everyman

Office worker

Wake up 0700

Breakfast:
Bowl of cereal and juice (300kcal)

Go to work 0830

Sit down
Answer telephone
Type documents
Walk to printer
Drink coffee (40kcal)

Lunchbreak 1300

Chicken sandwich
Crisps
Chocolate bar
Soft drink (800kcal total)

Finish work 1700

Gym 1800

5km (3.6mi) run

Dinner 1900

Jacket potato with tuna mayo and salad (500kcal total)

Relax at home 2000-2300

Bed 2300

Michael Phelps

Occupation: Swimmer (Olympic gold medallist)

Wake up 0630

Breakfast:
3 x fried-egg sandwiches
3 x chocolate-chip pancakes
5-egg omelette
3 slices of French toast
Bowl of grits (4,000kcal total)

Go to the pool 0800

2.4km (1.5mi) warm-up
4.1km (2.5mi) mixed strokes
Warm-down

Lunchbreak 1400

0.5kg (1lb) pasta
2 x ham-and-cheese sandwiches
Energy drinks (4,000kcal total)

Rest 1430

Go to the pool 1700

2.4km (1.5mi) warm-up
1km (0.6mi) mixed strokes
Warm-down

Finish training 2145

Dinner 2200

0.5kg (1lb) pasta
Large pizza
Energy drinks (4,000kcal total)

Bed 2300

Fuel: we all need it, but athletes need several times the calorific intake of the average person to sustain them during training

© Amadscientist

Super-human abilities

Football
You often hear people referred to as 'football geniuses', and there's more truth in that than you might at first think. Top-flight footballers are mental strategists akin to brilliant chess players.

Athletics
Runners need more fast or slow-twitch muscle fibres (depending on the event), throwers need core strength and hand-eye co-ordination, while jumpers need flexibility and leg strength.

Swimming
Swimmers with longer bodies and a bigger arm span than height, plus big hands and feet to propel them through the water, tend to perform better than others.

Modern pentathlon
As the pentathlon combines target shooting, fencing, swimming, equestrian show-jumping and cross-country running events, a pool of all-round Olympic ability is needed to succeed.

Table tennis
Fast-twitch muscle fibres and lightning reactions are a must, but the best players instinctively know where to plant their feet and have the endurance to last for several hours of intense play.

Cycling (road)
Cardiovascular endurance and strong legs are a given, but just as important is mental strength, helping you to keep going when a lesser athlete would give in.

have a natural leaning towards superhuman traits. For example, long limbs, a large pool (up to 90 per cent) of slow-twitch muscle fibres and a cardiovascular system with a huge range means Kenyans tend to dominate distance events over 5,000 metres (16,400 feet). Even outside of racial predispositions, and regardless of the best training techniques, some people are just genetically overqualified for a certain sport and will leave their fellow competitors for dust.

The Olympic Games themselves have also been a catalyst for Herculean achievements. Before the first modern Olympic Games under the International Olympic Committee in 1896, the first official world record for the 100-metre sprint (ratified by the International Association for Athletics Federations) was 10.8 seconds, set by Luther Cary in 1891. The benchmark ten-second barrier wasn't broken until 1968 and Usain Bolt smashed his own world record in Berlin in 2009 with a blistering 9.58-second run.

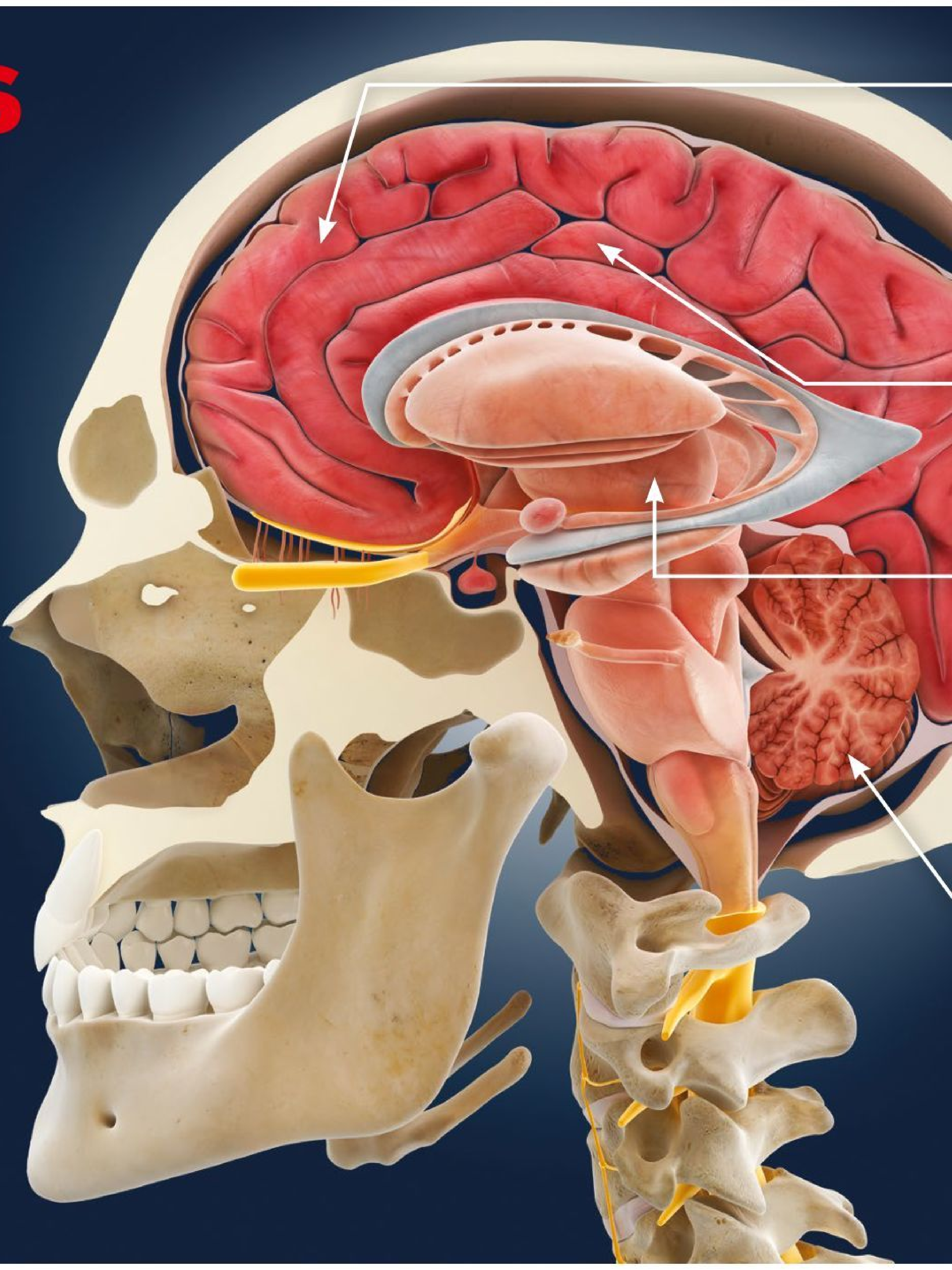
While over a century of socioeconomic improvements have helped open the Olympic achievements up to everyone, the Games themselves have provided a competitive platform from which Olympic athletes have been able to further distinguish themselves from the everyday man, proving they're capable of superhuman things.

Mental conditioning and focus are every bit as important for an athlete as being physically prepared for a sport

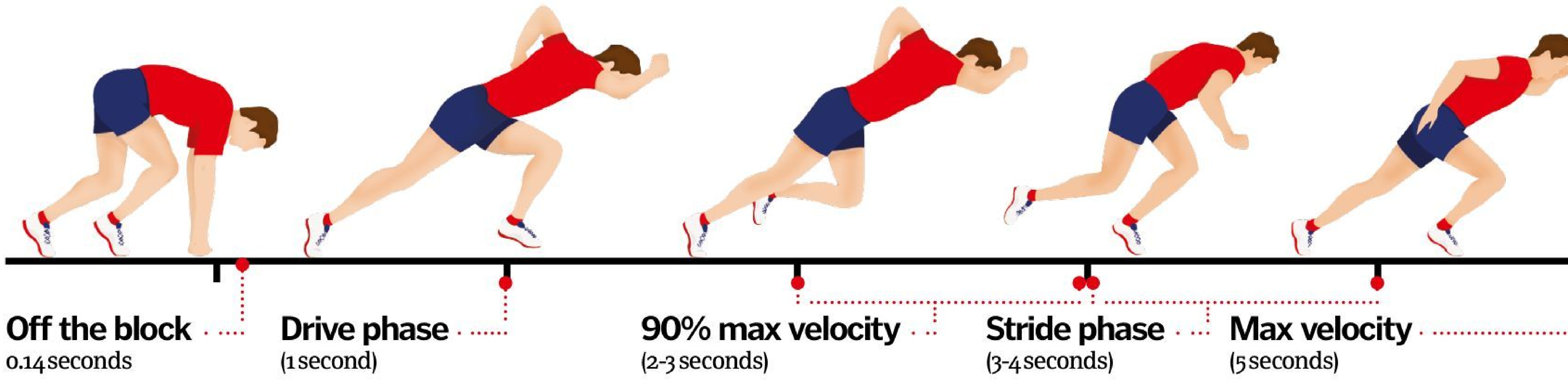
Mind Games

While most Olympic superhumans may not necessarily directly train their minds to enable them to perform at their peak, their brains will develop as a part of their training. Marksmen of the pentathlon and champion archers can't rely on 20-20 vision alone, for example. The hand-eye co-ordination that makes the perfect shot is quite methodical when you boil it down. It begins with the brain setting the bullseye as the goal, calculating the best way to achieve it and then predicting what kind of feedback sensation it should receive if the goal is achieved.

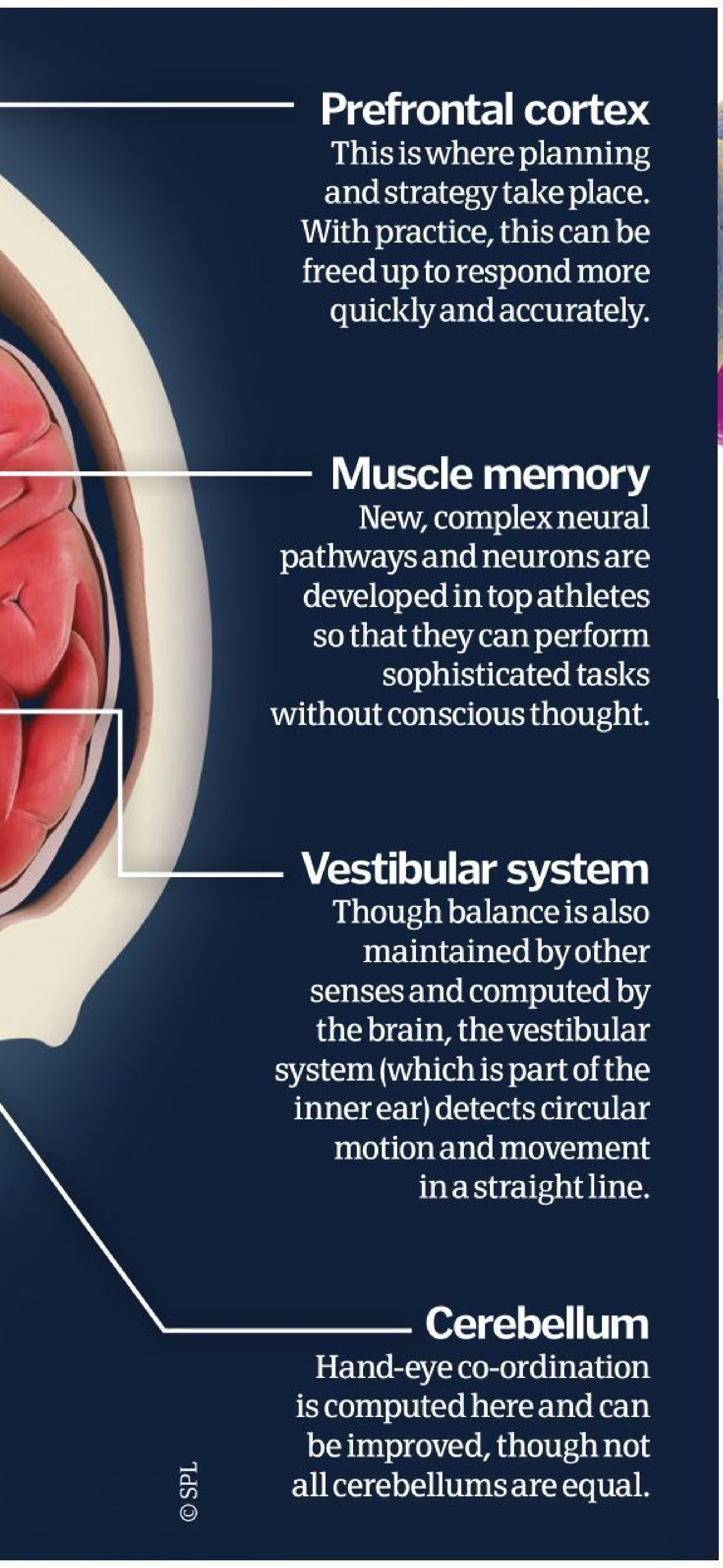
It rapidly adjusts the Olympian's form and compensates for what it thinks is the tiniest deviation from the right technique. All our brains do this even for the simplest of activities, but superhuman brains find more efficient, more accurate ways of doing the same task. The other critical factor in any Olympian's mind is their mental readiness for action. Being calm and focused is conducive to any activity and athlete brains emit stronger alpha waves than average, which indicate a state of calm. This is because the athlete has become efficient enough to free the prefrontal cortex in the front of the brain from the task at hand, giving it space to react. The anatomy of their brain has been changed, strengthening neuron connections in some areas and weakening them in others, honing it for the person's particular sport.



Ten seconds to gold



DID YOU KNOW? *The very first recorded Olympic event (in Greece, 776 BCE) was a 192m (630ft) dash*



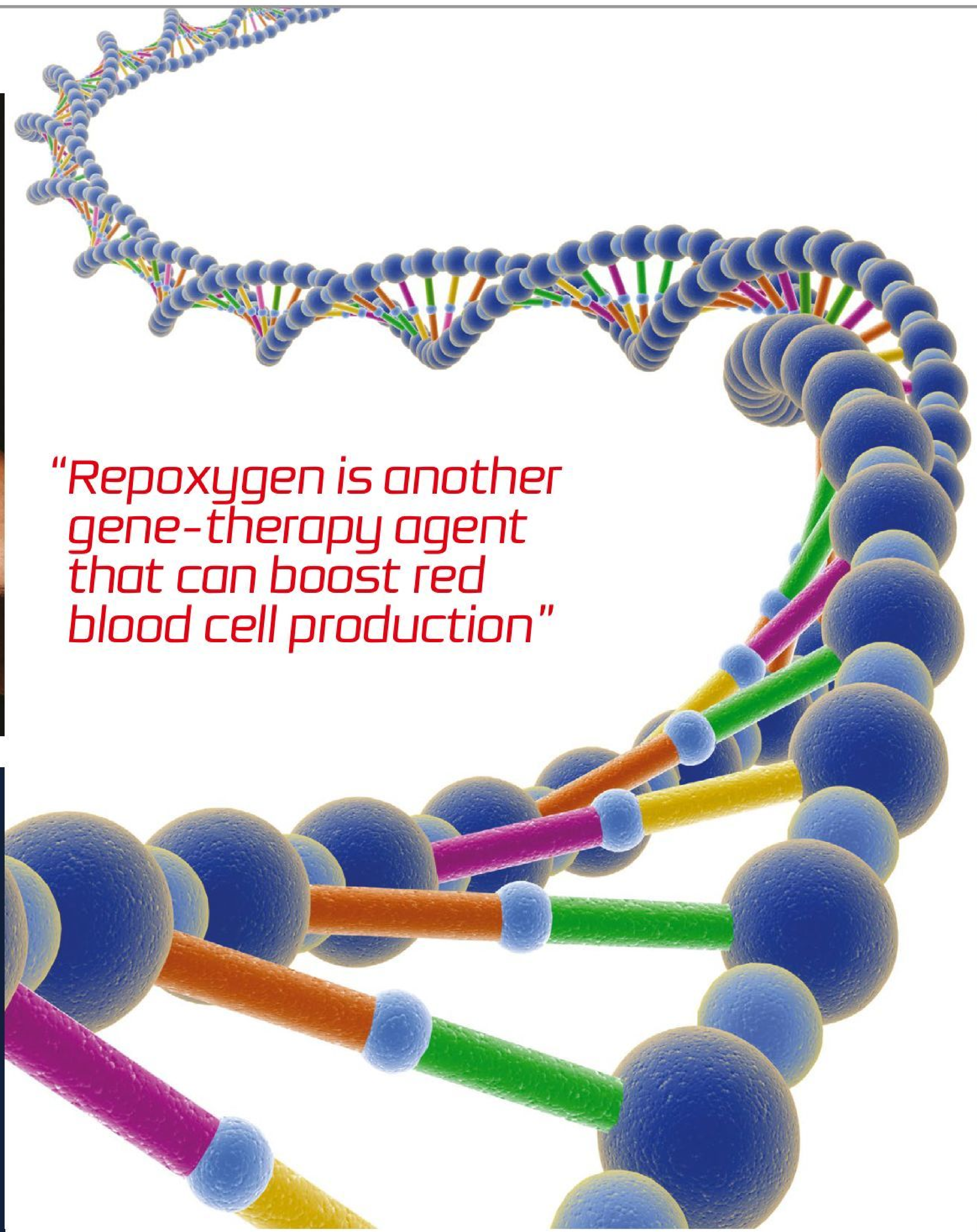
Prefrontal cortex
This is where planning and strategy take place. With practice, this can be freed up to respond more quickly and accurately.

Muscle memory
New, complex neural pathways and neurons are developed in top athletes so that they can perform sophisticated tasks without conscious thought.

Vestibular system
Though balance is also maintained by other senses and computed by the brain, the vestibular system (which is part of the inner ear) detects circular motion and movement in a straight line.

Cerebellum
Hand-eye co-ordination is computed here and can be improved, though not all cerebellums are equal.

© SPL

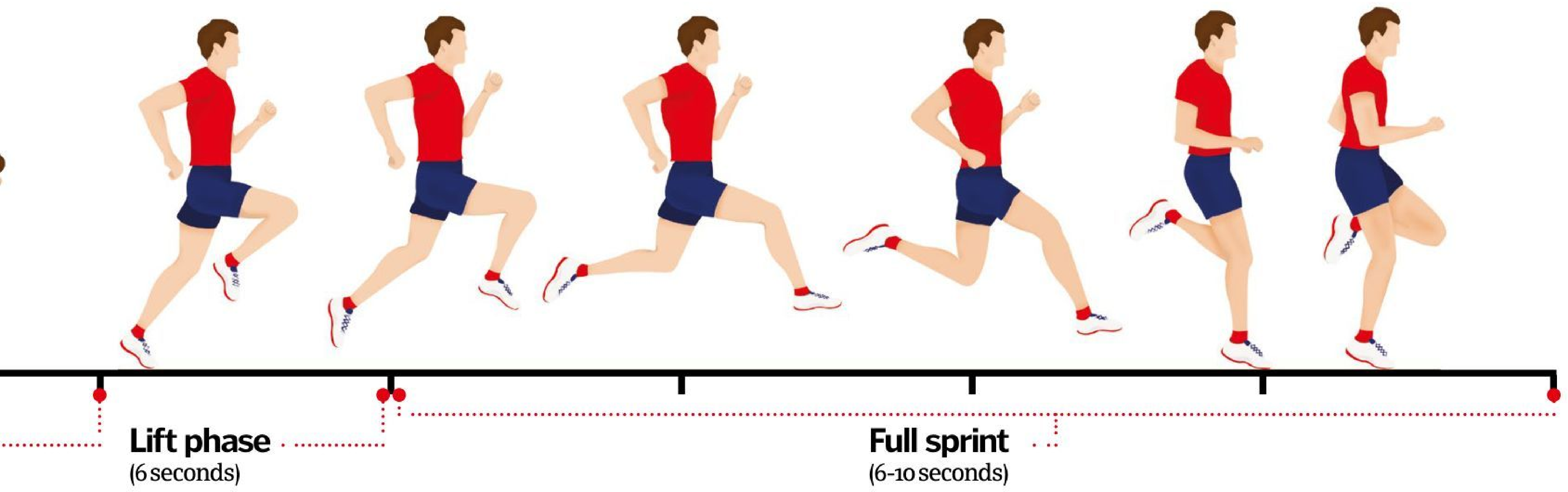


> *"Repoxygen is another gene-therapy agent that can boost red blood cell production"*

It's all in the genes

Currently, the only way we can take charge of our own destiny and give ourselves a fighting chance of competing in the Olympic Games is by hard work and dedication – though that doesn't guarantee we'll even come close to becoming Olympic-standard. Modern technology may change that however: 'gene-doping' is the term given to a wave of genetic technologies that may allow an athlete to change their DNA in favour of becoming faster, stronger and all-round better at their event. PPAR-ð (peroxisome proliferator-activated receptor alpha) affects muscle-cell metabolism and can potentially boost strength and power, as well as affect fat metabolism for a leaner physique. Repoxygen is another gene-therapy agent that can boost red blood cell production, increasing the amount of oxygen delivered to the muscles.

Even though either of these might put the average person on a genetic par with Olympic superheroes, using them to increase performance in professional sports is illegal, akin to using anabolic steroids and other banned substances. Currently, however, there's no way to test for such gene-altering drugs.



Lift phase
(6 seconds)

Full sprint
(6-10 seconds)

Super-human abilities

Gymnastics (artistic)
Incredible balance and flexibility aside, more than any other athlete, gymnasts require a strength-to-weight ratio that belies their slight frame.

Rowing
Again, long, strong limbs make for the longest strokes and the best rowers. Olympic rowers need to overcome lactic acid burn from anaerobic bursts that would cripple lesser men.

Boxing
Unlike most other Olympic sports, boxers are expected to endure a degree of injury to the head and body, yet continue performing at their peak. In addition to overall athletic ability, an iron jaw and a certain 'grit' are vital.

Weightlifting
Weightlifters are extreme specialists, focusing large overall muscle mass into feats of power and strength. Technique and endurance should never be underplayed, as only a flawlessly executed lift will secure full marks.

Archery
Archers need long, strong arms and back muscles, hawk-eye vision and focus to the point that the archer can temporarily lower their heart rate.

Diving
More than any other event, concentration and absolute focus are vital to a diver, because entering the water from such lofty heights with the wrong posture can be seriously dangerous.

The truth about hair transplants

How this surgical technique battles baldness

Male pattern baldness is common, although in some people it can lead to concerns over appearance and even a severe loss of confidence. Most choose to accept it, but others are fighting the balding process. Modern science has recently updated ancient techniques, meaning that hair transplants can now reliably restore normal hair patterns.

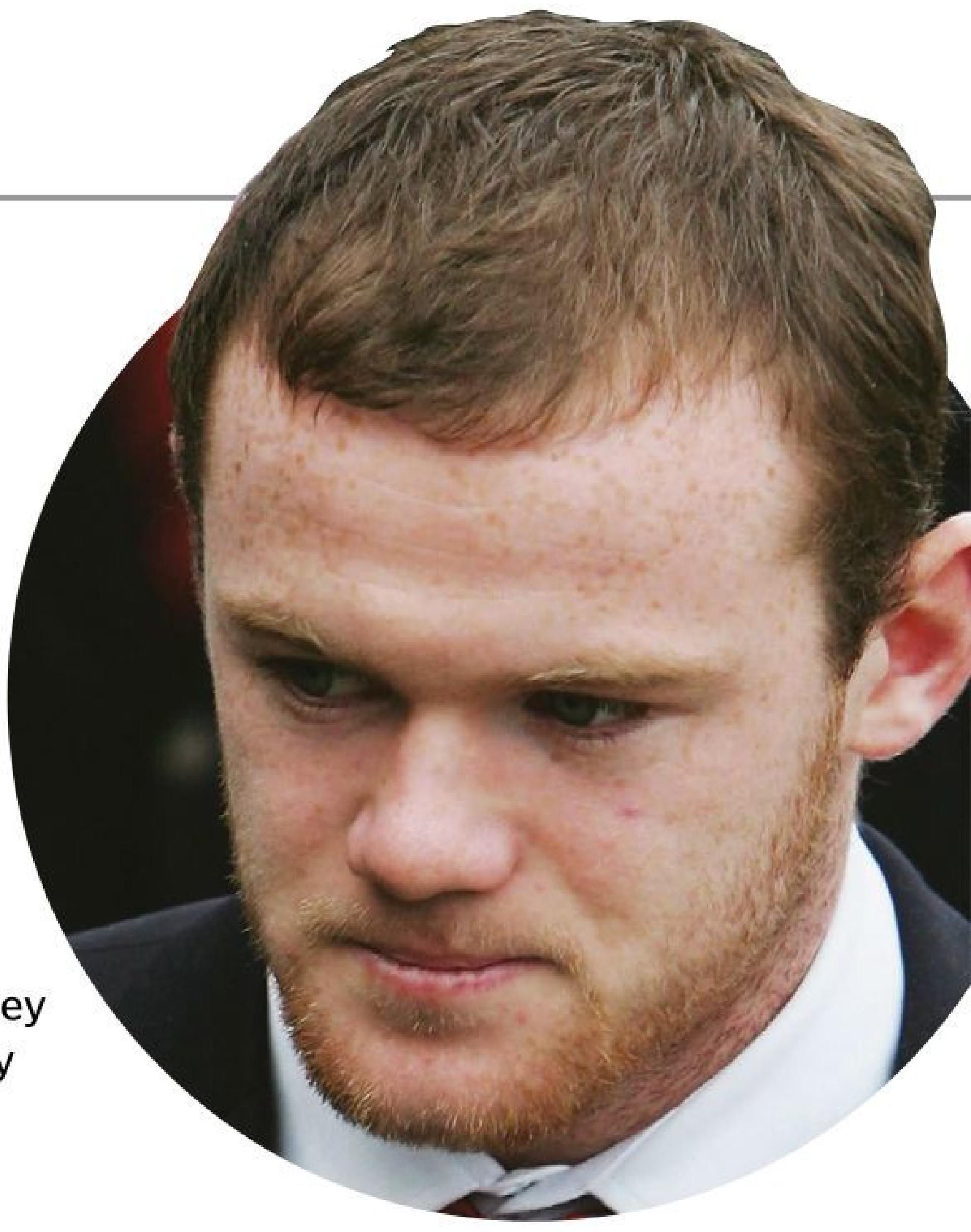
Patients are carefully screened before undergoing hair transplantation, similar to patients before any cosmetic procedures. While hair transplants can restore self-confidence, it's important that they aren't used to fix problems in patients' lives that can't be solved through a change in appearance alone.

Hair transplants have been practised as far back as the 19th century. However, it is only in the last 20 years that modern techniques have led to reliable and realistic results. Currently, two techniques are used the most. The first involves taking a thin strip of hair from the back of the scalp, removing the hair follicles and implanting them to the front of the hairline. The second doesn't involve removing a strip; rather, small units of two to four follicles are removed and then transplanted in the required area.

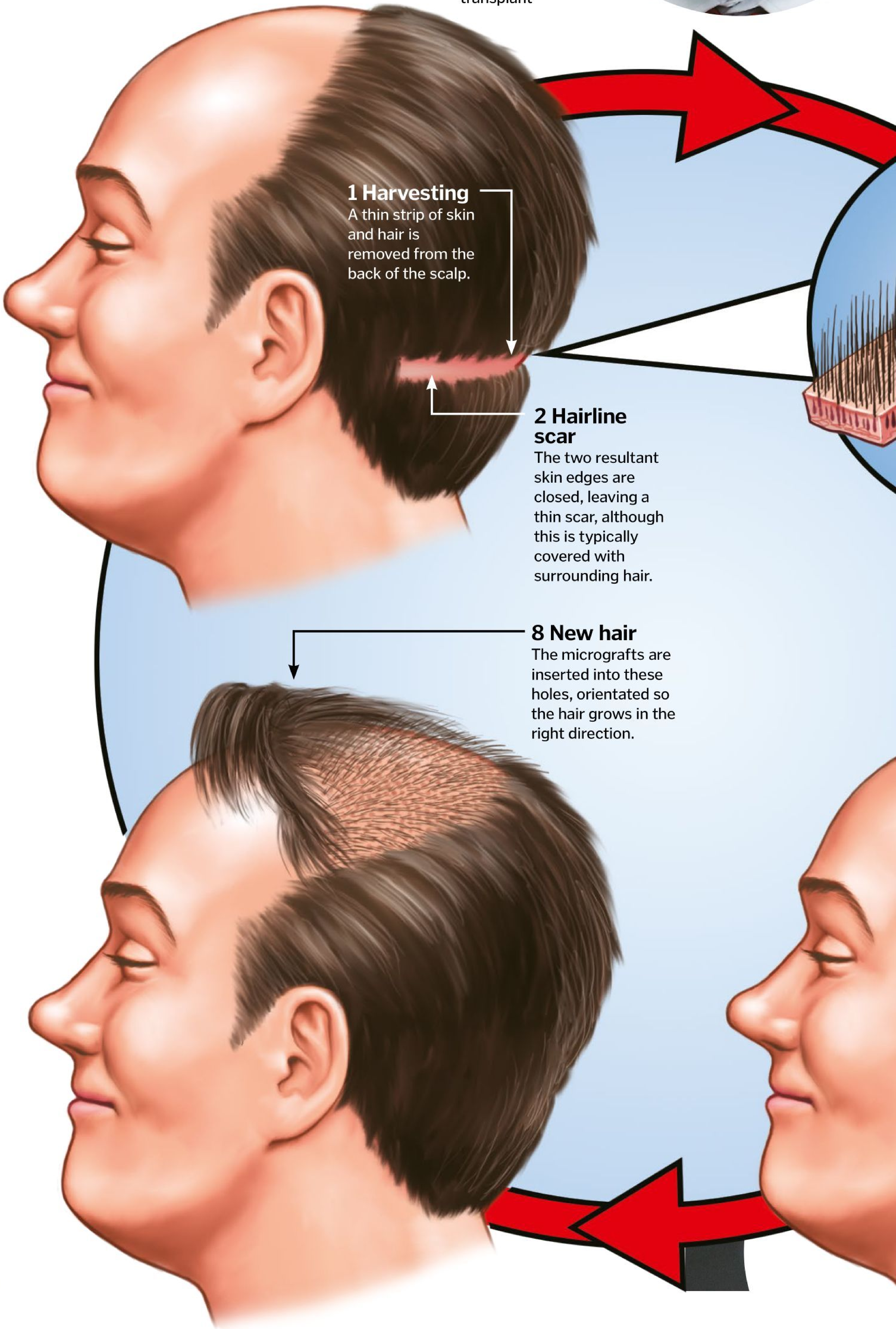
These techniques have become so sophisticated that the direction of the hair follicle is controlled when implanting it in the new site. This gives a natural hair-growth direction and a realistic pattern. These procedures aren't without risks, though. They can be painful, and as with any surgical wound, infection can set in. There is also no guarantee of success as baldness can recur. However, it is a generally successful procedure and can restore lost confidence.

How to perform a hair transplant

The basic steps in performing a strip harvest of hair, the most commonly used method



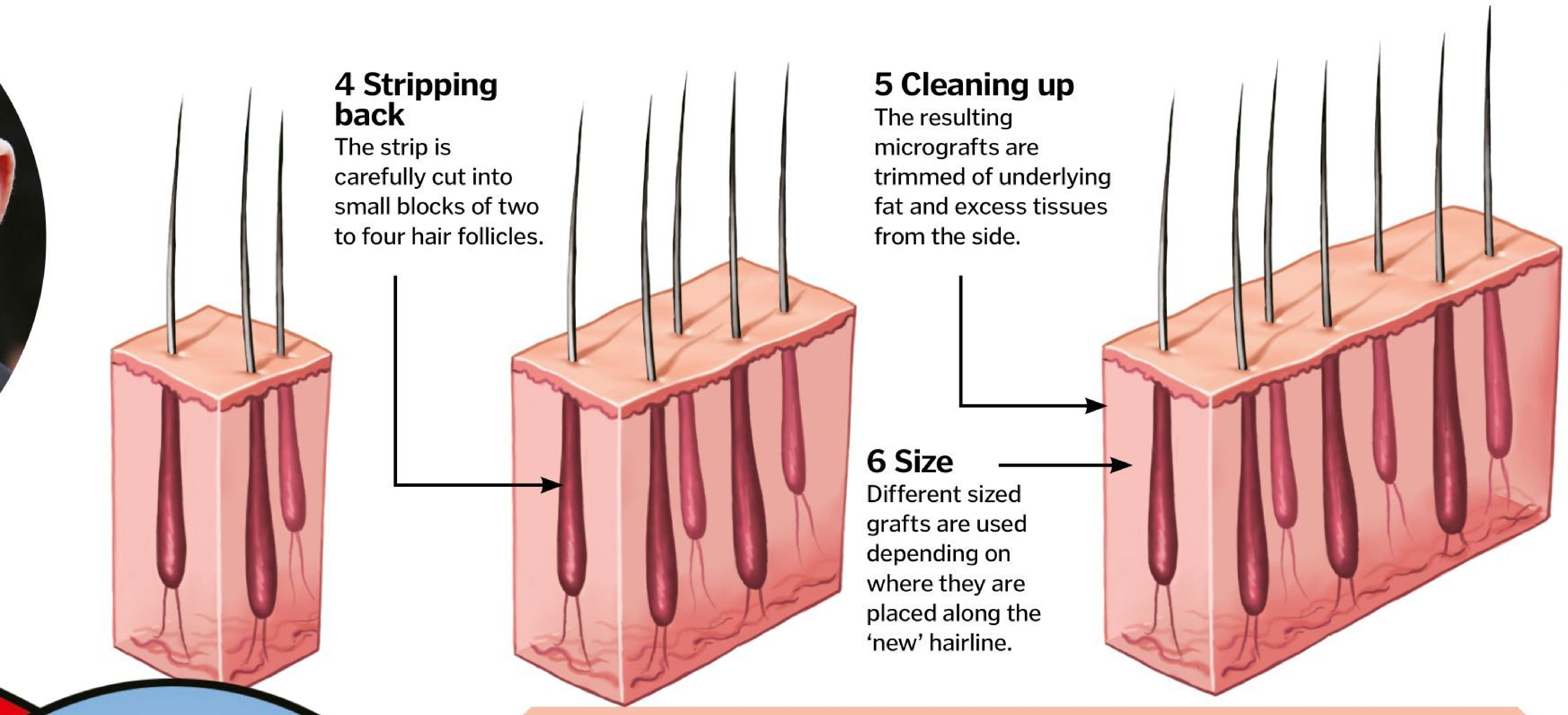
Footballer Wayne Rooney has famously had a hair transplant



1 Harvesting
A thin strip of skin and hair is removed from the back of the scalp.

2 Hairline scar
The two resultant skin edges are closed, leaving a thin scar, although this is typically covered with surrounding hair.

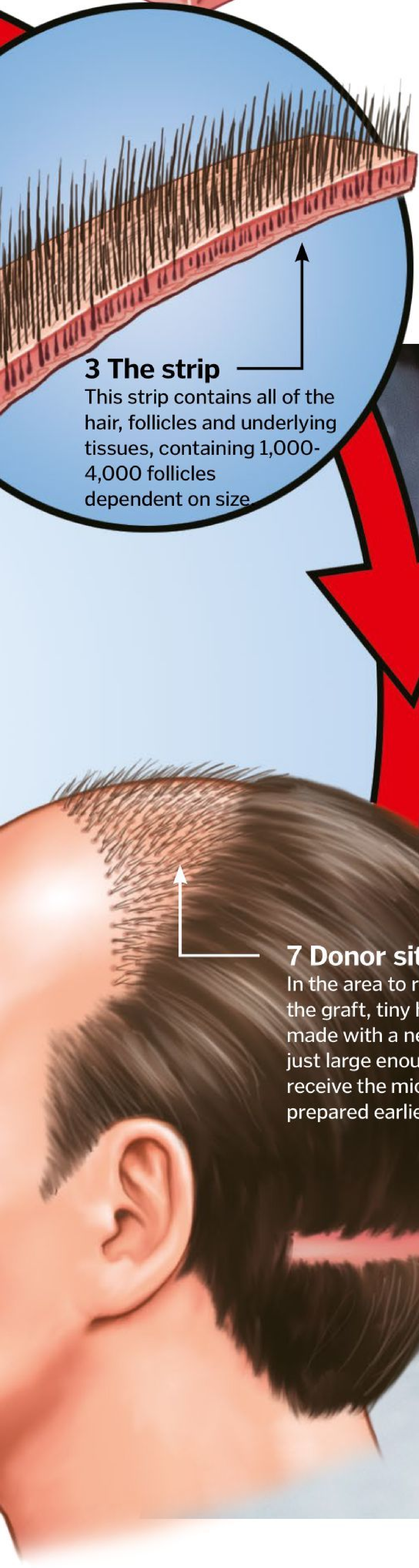
8 New hair
The micrografts are inserted into these holes, orientated so the hair grows in the right direction.



4 Stripping back
The strip is carefully cut into small blocks of two to four hair follicles.

5 Cleaning up
The resulting micrografts are trimmed of underlying fat and excess tissues from the side.

6 Size
Different sized grafts are used depending on where they are placed along the 'new' hairline.



3 The strip
This strip contains all of the hair, follicles and underlying tissues, containing 1,000-4,000 follicles dependent on size

7 Donor site
In the area to receive the graft, tiny holes are made with a needle, just large enough to receive the micrografts prepared earlier.

Compare the two types of procedure

The two most common techniques are strip harvesting and follicular unit extraction (FUE). Strip harvesting involves a strip of skin and hair being surgically removed from the back of the scalp. Although it is successful and fast, it requires a general anaesthetic and leaves a small scar.

FUE is done under local anaesthetic and takes longer; sometimes two to three treatments on separate days. Individual hair follicles are stripped out using a special device and then implanted in the front of the scalp. There's no scar or need for general anaesthetic, and it's very precise.

How hair is lost

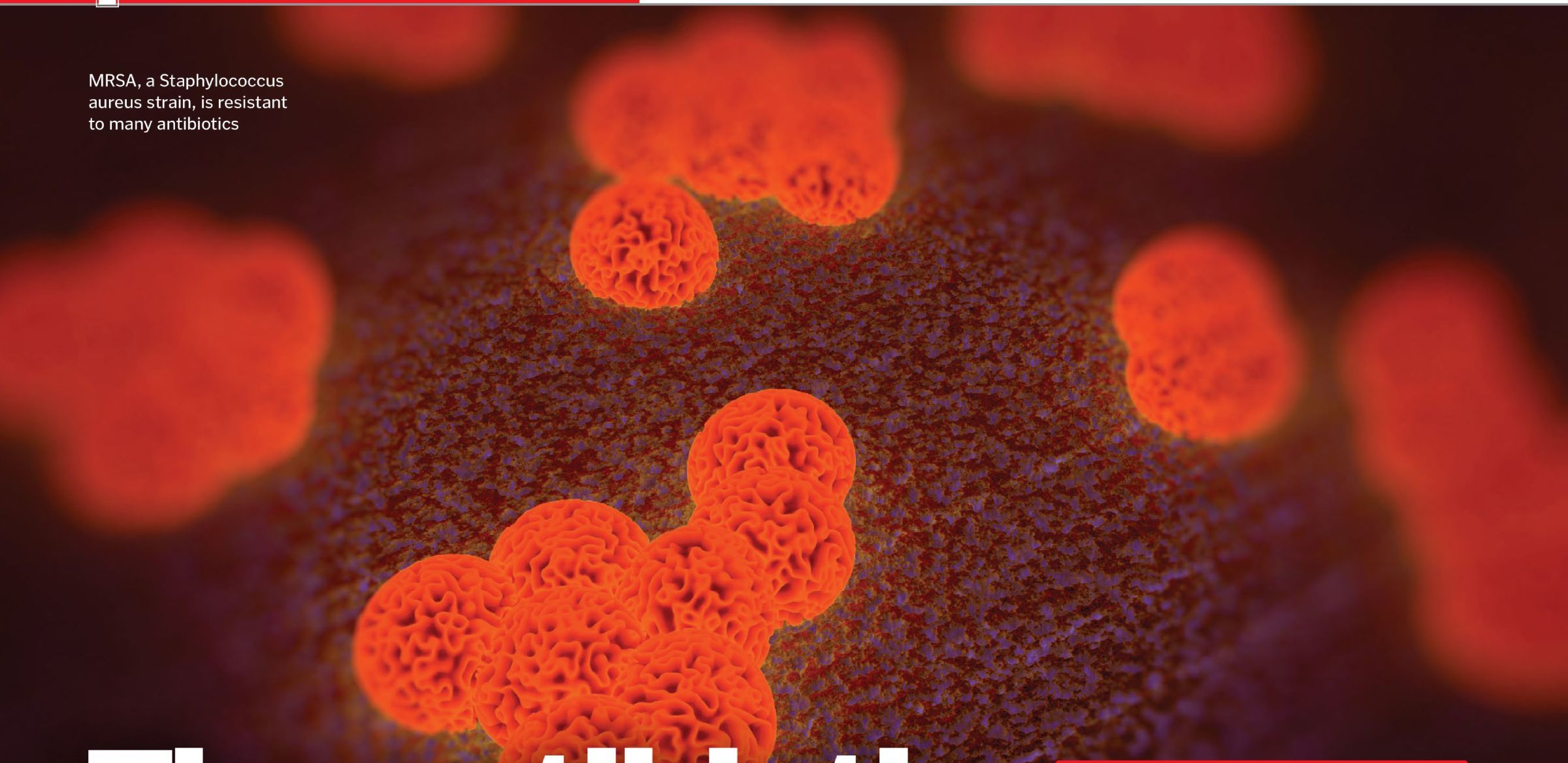
The most common type of baldness is male pattern baldness, which can affect 50 per cent of men over the age of 50. Typically, the hair on the temples thins while the hair on the top of the head recedes. It usually takes around ten years for the hair to recede fully, leaving a small rim around the sides and back.

Changes in signalling of the male sex hormone dihydrotestosterone (DHT) is primarily responsible. The hairs on the head become susceptible to it, which causes thinning and then hair loss. Why the chest or beard hair isn't affected is unknown. This type of age-related baldness can affect women too, but is less common.

Different types of hair loss also exist. These include patchy hair loss on the scalp (leaving tufts), loss of all body hair (head, chest, arms and legs), and universal hair loss (all hair including eyebrows and eyelashes).

Hair transplant science has improved greatly in the last 20 years

© Alamy; Thinkstock; The Art Agency/Tom Connell



MRSA, a Staphylococcus aureus strain, is resistant to many antibiotics

The antibiotic apocalypse

Are we heading towards a future where infections are immune to treatment?

We have a major problem. Since the dawn of humanity, we have been locked in a battle with microscopic organisms, and just when we thought we were starting to win, they're fighting back.

Bacteria cause some of the most devastating human diseases, from typhoid fever to tuberculosis, and until the 1920s, we were utterly defenceless. But when Alexander Fleming ushered in the age of the antibiotic with his discovery of penicillin, we suddenly had a powerful weapon.

Antibiotics work by stopping bacteria from dividing, or by killing them outright. Thanks to them we can treat infections that were once fatal, we can perform complex surgery, and we can mass-produce food on an unprecedented scale. But we have used them and used them and used them, and the bacteria have started to learn.

These little organisms can replicate in a matter of hours, and each time they do, they make tiny, accidental tweaks to their genetic code. Some tweaks aren't useful, but very occasionally, a mistake is made that helps one bacterium to outlast an onslaught of antibiotics for just a little longer than their neighbours.

When the course of antibiotics is finished, and all of the vulnerable bacteria are dead, this slightly stronger individual can carry on dividing, making a new colony that is a little bit better at avoiding the effects of the drugs. And if this happens time after time, you have a superbug on your hands.

Worse still, bacteria are able to share useful genes with their neighbours. And not just members of their own species. They carry useful snippets of genetic code in little rings of DNA called plasmids, and they can swap these like trading cards, passing resistance on to others around them.

Using these tactics, several strains of bacteria are now able to evade almost all of the antibiotics in our arsenal. We're in the middle of a microscopic arms race, and the future of medicine is hanging in the balance.

Antibiotics are used everywhere, from hospitals to intensive farms

What needs to be done?

Ensuring that effective antibiotics are available for future generations is a mammoth task. We need to stop giving bacteria the opportunity to see our best treatments.

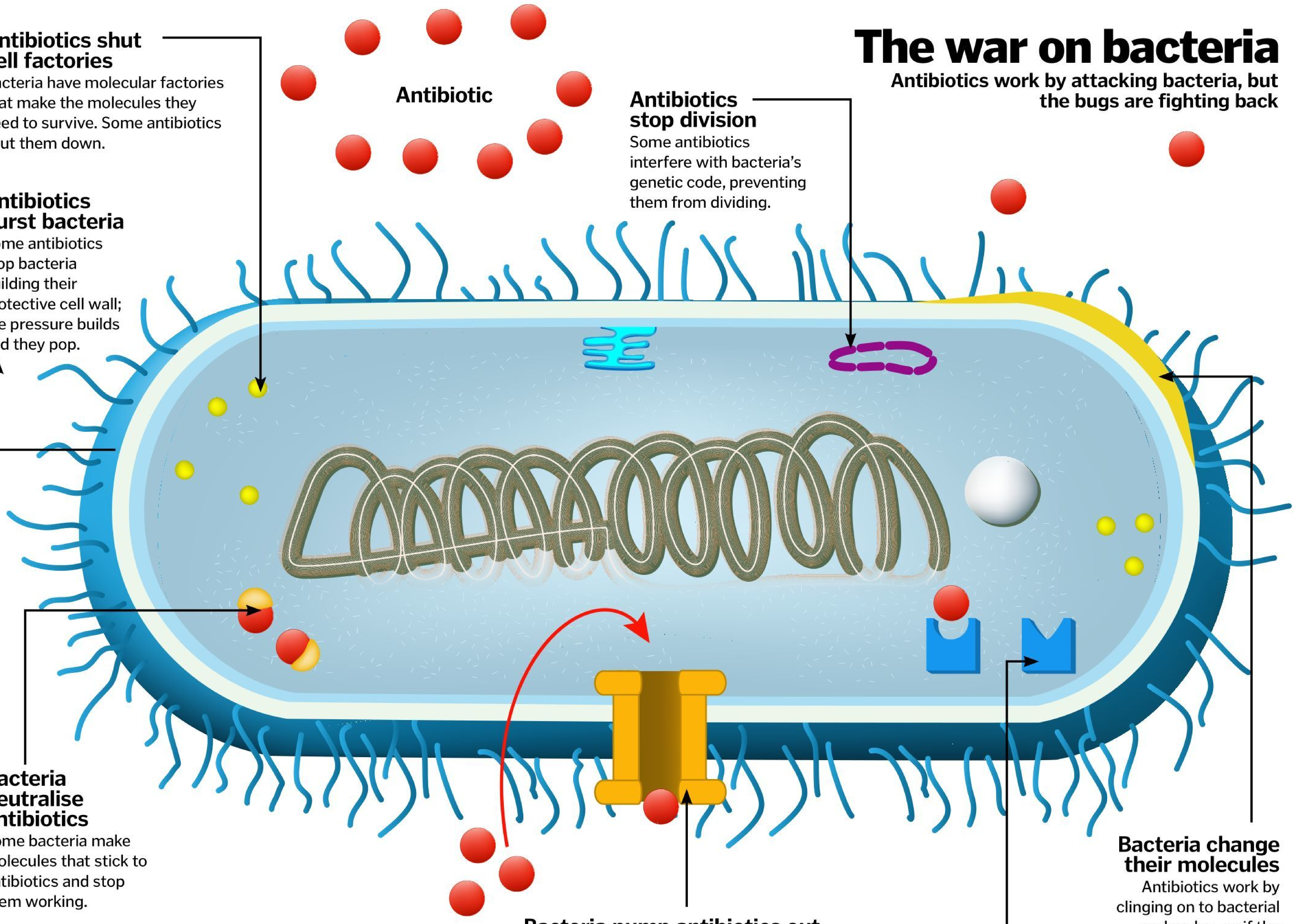
Vets and doctors are being urged to only use antibiotics if absolutely necessary, and to test their patients beforehand to check that the treatment will definitely work to kill the infection. Patients are being asked to always finish their full course of antibiotics, even if they feel better, to ensure that any lurking bacteria have been cleared up. Farmers are being encouraged to keep their livestock clean and vaccinated rather than use antibiotics to control disease. Governments and development organisations are under pressure to regulate and monitor antibiotic use, and to make sure people have access to the right antibiotics. And the medical research community are racing to find new drugs to fight resistant strains.

Rather than throw antibiotics at any infection, we need to choose our battles carefully.

DID YOU KNOW? *The first antibiotic, penicillin, was discovered by accident when a blob of mould got into an experiment*

The war on bacteria

Antibiotics work by attacking bacteria, but the bugs are fighting back



Antibiotics shut cell factories

Bacteria have molecular factories that make the molecules they need to survive. Some antibiotics shut them down.

Antibiotics burst bacteria

Some antibiotics stop bacteria building their protective cell wall; the pressure builds and they pop.

Antibiotics stop division

Some antibiotics interfere with bacteria's genetic code, preventing them from dividing.

Bacteria neutralise antibiotics

Some bacteria make molecules that stick to antibiotics and stop them working.

Bacteria pump antibiotics out

If antibiotics do get inside bacteria, some are able to pump them straight out again.

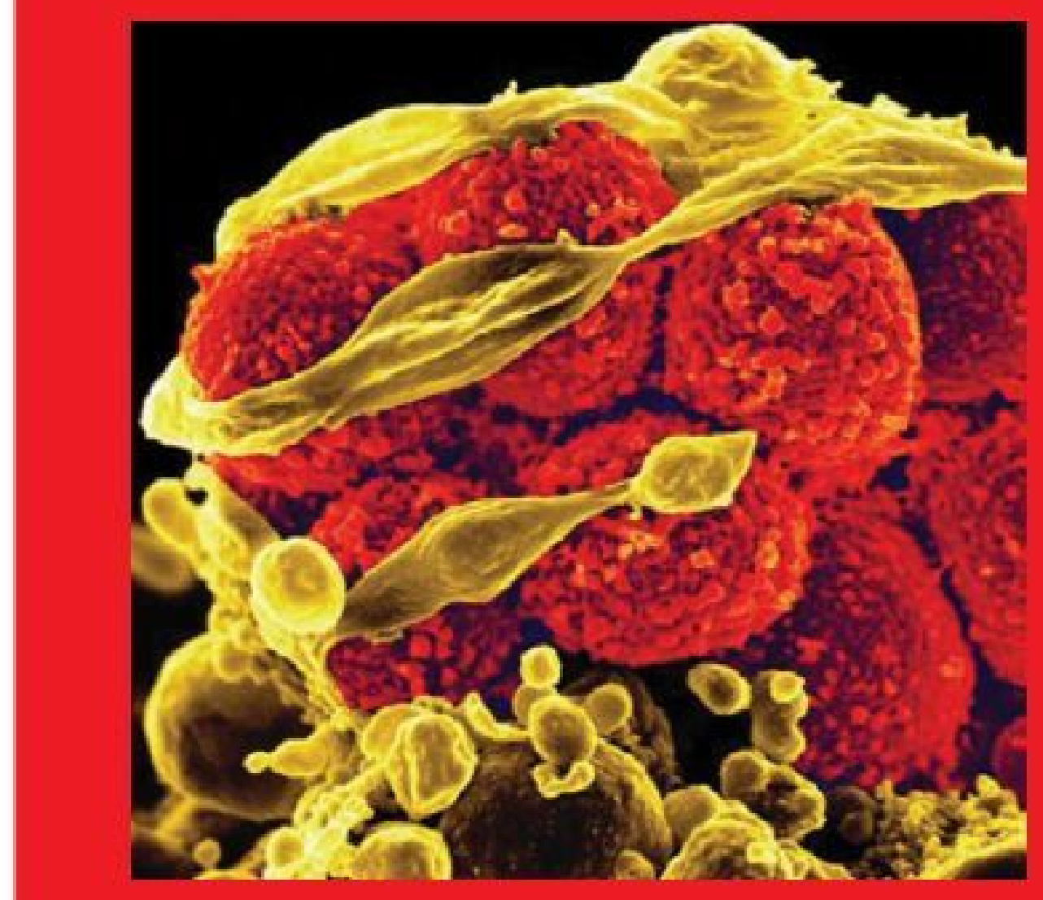
Bacteria block antibiotic entry

Some bacteria have developed ways to stop antibiotics from getting through their cell walls.

Bacteria change their molecules

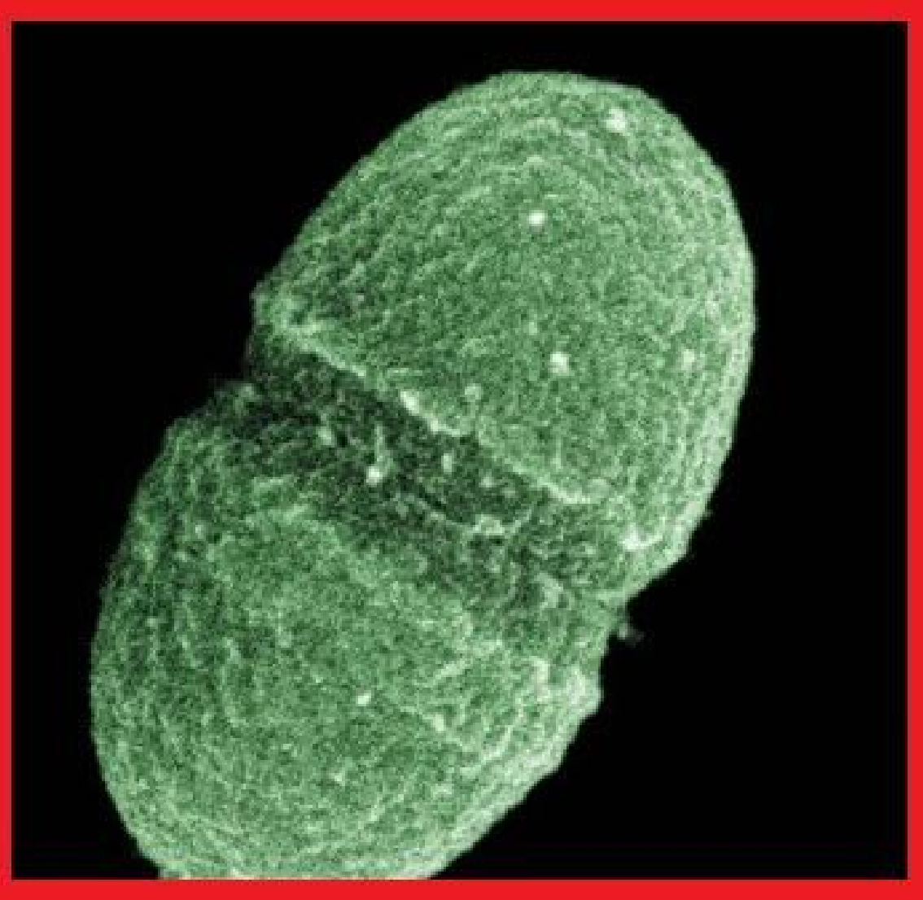
Antibiotics work by clinging on to bacterial molecules, so if the bacteria can change their shape, they can sometimes escape.

Superbug lineup



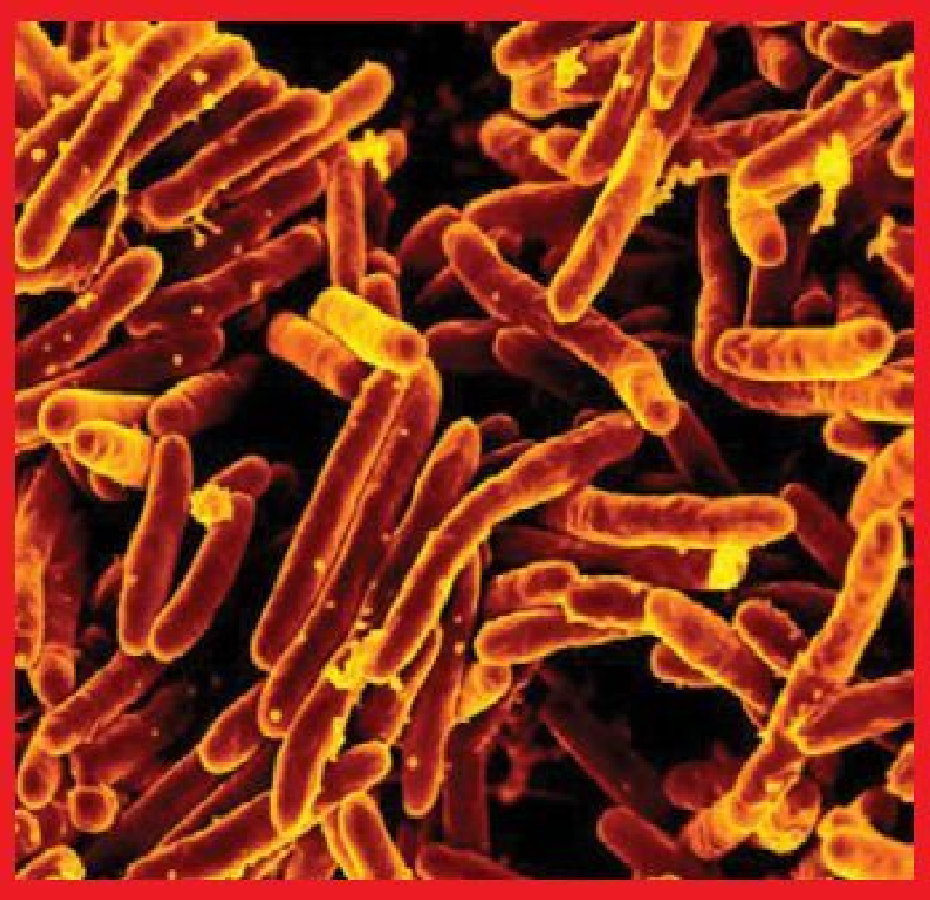
MRSA

Methicillin-resistant Staphylococcus aureus (MRSA) is the most infamous of all superbugs. Regular Staphylococcus aureus is a common type of bacteria, normally found harmlessly on the skin. This bug first started resisting the effects of antibiotics as far back as the 1950s, however, and MRSA itself first appeared in 1962.



VRE

Vancomycin-resistant Enterococcus (VRE) are immune to the effects of one of our most powerful antibiotics. Vancomycin is usually reserved for the most serious of infections, including meningitis and MRSA. These superbugs were first spotted in the 1980s, and have proven very good at developing resistance to any new antibiotics thrown at them.



MDR-TB

Multi-drug-resistant Mycobacterium tuberculosis (MDR-TB) does not respond to the two most powerful anti-tuberculosis drugs currently available - rifampicin and isoniazid. Normal treatment for TB involves a combination of antibiotics taken for six months, but if the drugs are given alone, or stopped too soon, resistance can develop.

KPC

Klebsiella pneumoniae carbapenemase-producing bacteria (KPC) are a relatively new problem, first identified in the USA in the early 2000s. They are very good at resisting treatment, and also produce an enzyme that allows them to break down carbapenem, a powerful antibiotic that's one of our last lines of defence.

Learn more

Arm yourself with information

Knowledge is the most powerful weapon we have against an antibiotic apocalypse, here are two top places to learn more:

- **The World Health Organisation**
  www.who.int
  Working in over 150 countries, the World Health Organisation are leading the fight against antibiotic resistance. Their social media accounts are a great place for bite-sized news and updates.

- **Bugs and Drugs**
  www.antibioticresistance.org.uk
  With funding from the British Government's Department of Health, the National Electronic Library of Infection have made a one-stop hub of information about antibiotic resistance.

© Thinkstock

Why do we get fat?

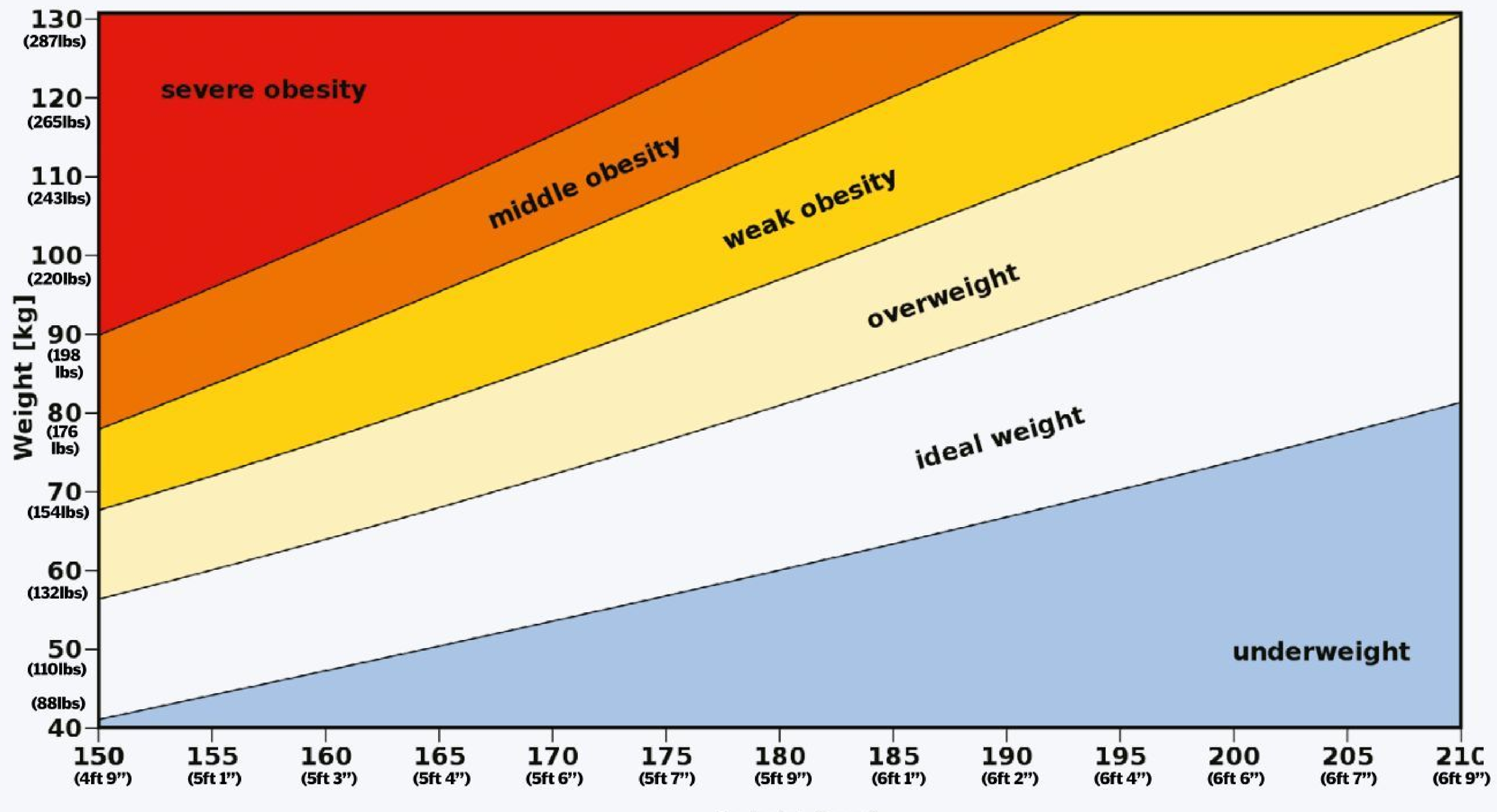
As the obesity epidemic grows, it is important to understand just what causes us to gain weight

Daily calorie intake for an average adult is set between 2,000 and 2,500kcals and recommended fat intake is between 70 and 90 grams. The body needs this level of calories in order to function at maximum efficiency. However, if we consume more than is needed to run our body, it stores these extra calories as fat. These fat stores can serve as a reserve if we don't eat enough, but if someone consistently over-eats, they'll become overweight as the body continues to store the excess calories.

Obesity is becoming more prevalent across the world, within developed and developing countries. Highly calorific food and snacks, with generally poor nutritional value, have become more widely and cheaply available and the amount of saturated fat being consumed by an average adult is much higher than 20 years ago. Changes in behavioural patterns of societies have also contributed to the problem as average levels of physical activity have reduced. Eating patterns have also changed due to lifestyle changes. Busy lives and more focus being placed on careers has led to the advent of the 'ready meal' and an increase in the number of takeaways eaten – which are often very high in saturated fat and calories. Genes can also have an impact on weight gain, but most cases of obesity that we see are actually due to average calorie intake increasing, with actual need reducing.

Over the last 20 years, child obesity levels have also been increasing dramatically, again primarily due to physical exertion decreasing and calorific intake increasing. This is of particular concern because of the many health problems associated with obesity such as type 2 diabetes, cardiovascular disease, strokes and certain forms of cancer among others.

Working out your body mass index (BMI)



© Bibi Saint -Pol 2008

Immunisation: how it keeps you healthy

Your body has the tools to keep you safe from disease

The vaccination process in action

Before the vaccine, everyone got chicken pox. You'd get it once as a kid and then wouldn't get it again. This is a perfect example of immunisation. Antigens are foreign molecules that when introduced, the body recognises as an 'intruder' and fights with antibodies, creating an immune response. Antibodies neutralise the antigen so that the next time around they know what to do. Vaccinations make immunisation even more convenient because you don't even have to get sick the first time around while your antibodies do their work.

Vaccines carry inactive bacterial toxins, killed microbes, parts of microbes, and weakened microbes. Basically, enough 'stuff' to catch your antibodies' attention, but not enough to make you sick. Nowadays, instead of actually having chicken pox, kids often get the vaccination, therefore avoiding the itchy bumps and fever but creating the 'immunological memory' needed to fight it the next time it tries to invade the body. Vaccinations have led to the eradication of smallpox and are coming very close to eradicating polio worldwide.

Vaccinations and natural immune responses are called 'active immunity' because it requires the work of your immune system. 'Passive immunity' occurs when actual antibodies are transferred from one person to another. An example is when a mother breast-feeds her infant, transferring her own natural resistance to certain antigens in her baby. Passive immunity only lasts up to a few months. After that, the baby's own immune system has hopefully strengthened to be able to fight antigens on its own. Another use for passive immunity is in rabies cases. Someone bitten by a rabid animal does not have enough time to allow for an active immunity response to a vaccine, so they are given antibodies from someone who has been vaccinated to fight the virus in the interim.

DID YOU KNOW? *The tongue and the inside of the mouth are the fastest healing parts of our bodies*

How do we heal?

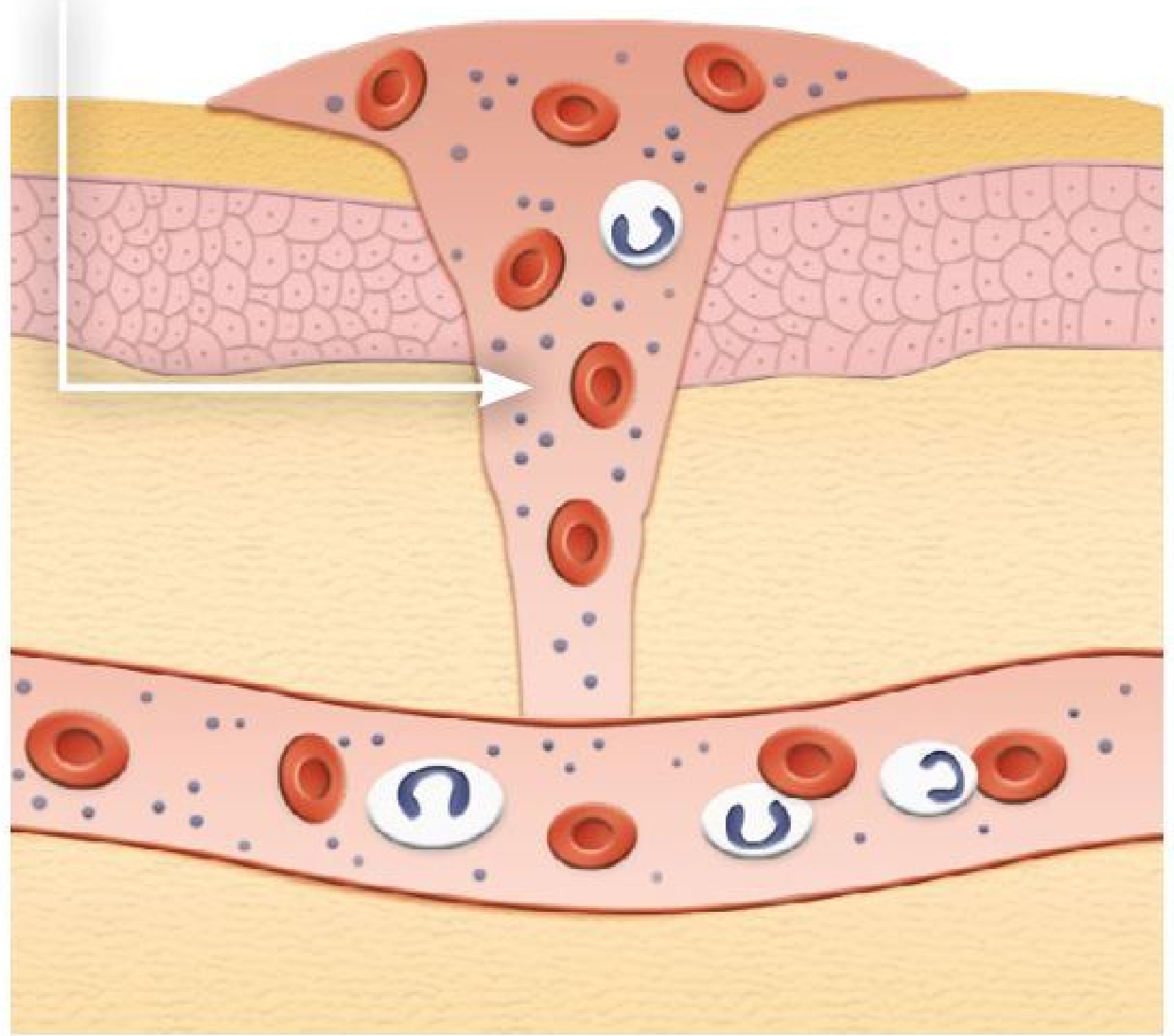
We always expect our bodies to heal when we injure ourselves, but how does this happen?

Healing can be defined as the restoration of injured tissue back to usual function. There are two main ways in which tissue heals; regeneration and repair. Healing involves the removal and replacement of damaged tissue, and most organs will use both methods to fix damage – although cardiac muscle cells and neurons are examples of cells that cannot use regeneration.

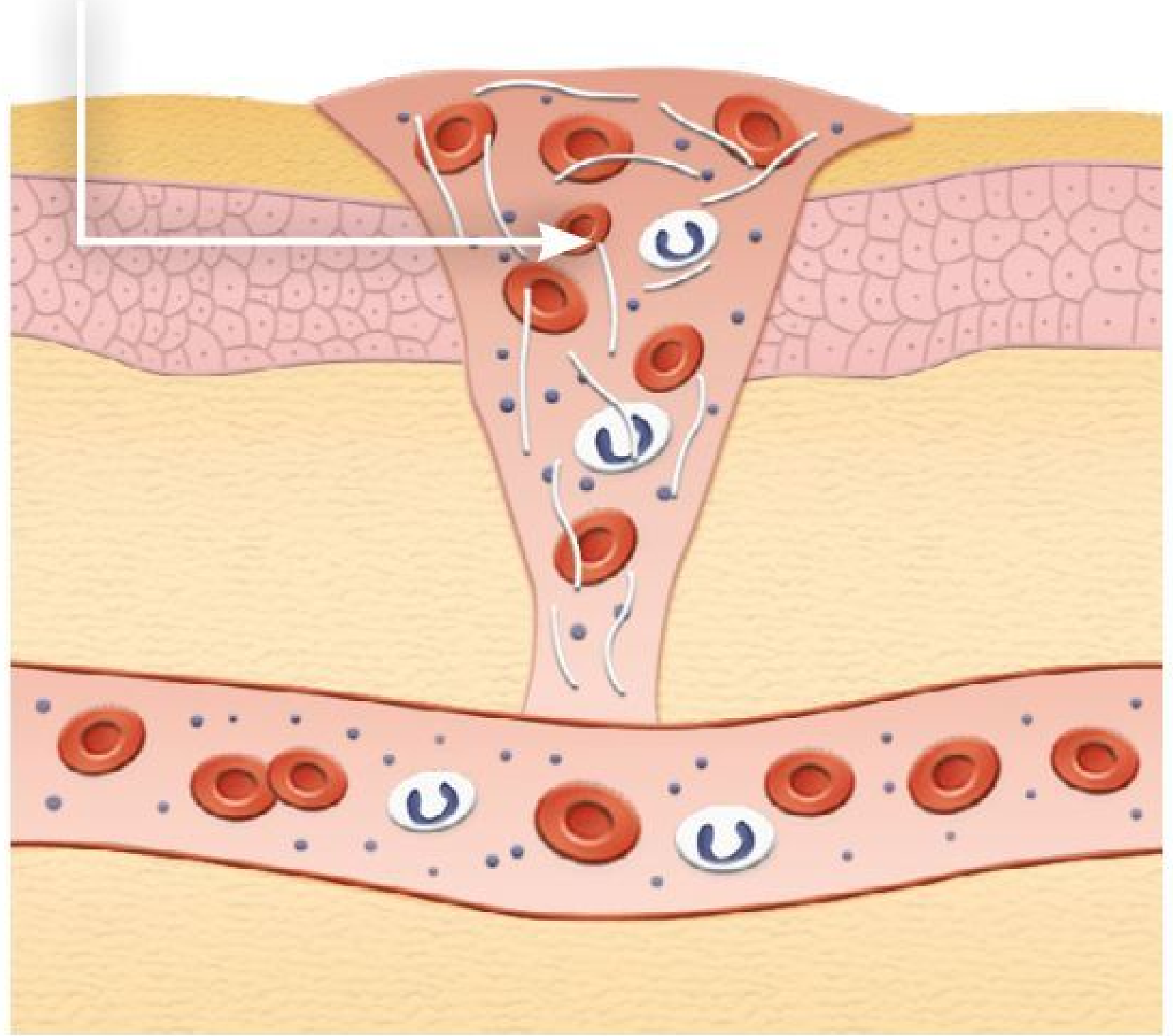
Regeneration is when cells replicate within the same tissue mass that was damaged. These then replace the cells that have been damaged or died. Most cells in the body can repair damage in this manner, but the surrounding collagen network must remain in good condition for this to be able to occur.

Repair takes place when the damaged tissue cannot replicate cells of the same type, and scar tissue is then formed. Repair is made up of three stages; the inflammatory phase, the proliferative phase and the maturation phase. The inflammatory phase is when bacteria is killed off by macrophages and phagocytic cells and growth hormones released encourage cell growth in the area of damage. The following stage is when the wound starts closing up and filling with collagen, which will form the scar tissue. During the final maturation phase, healing tissue is replaced with stronger collagen and unnecessary tissue produced during the earlier phases is removed.

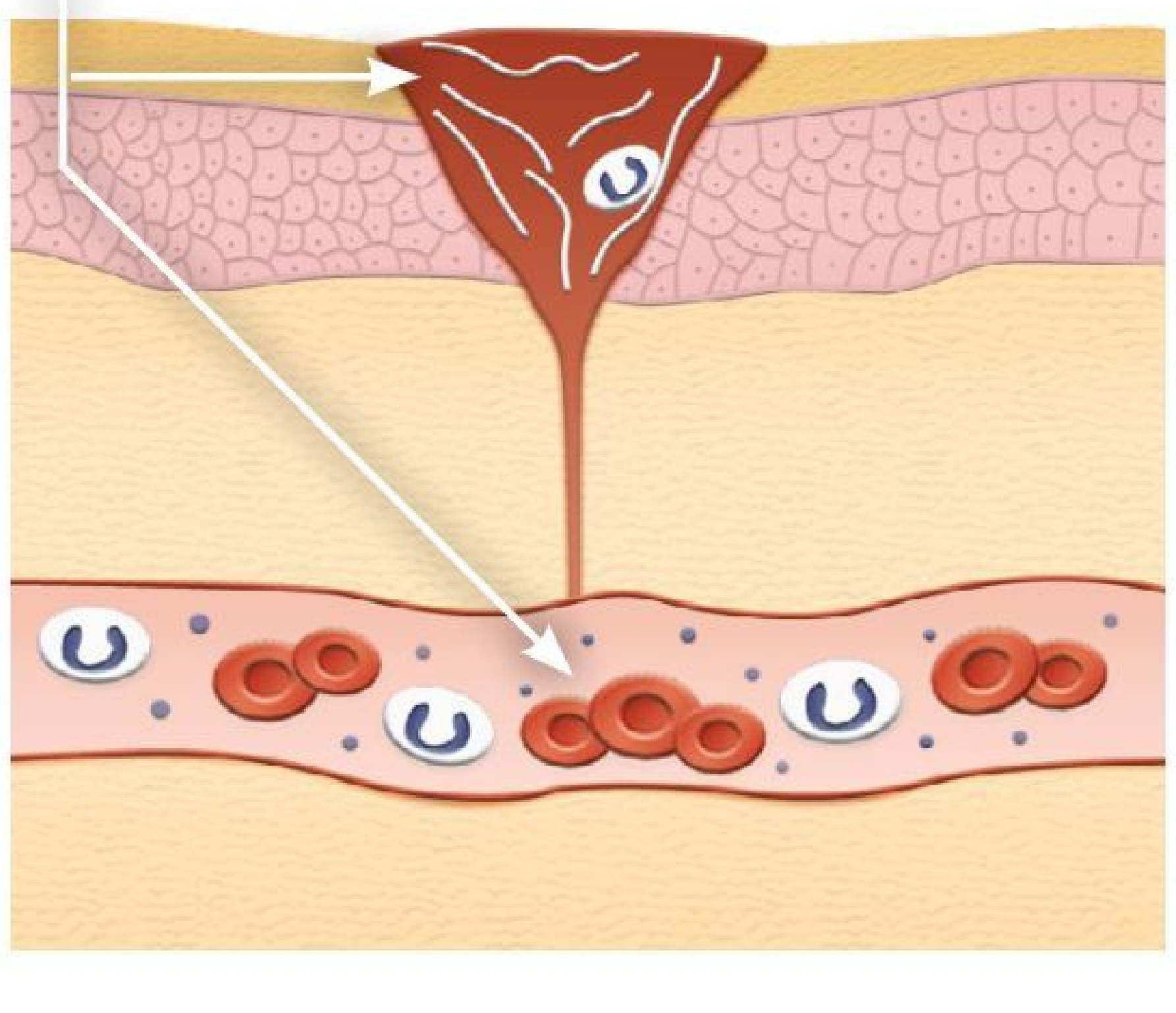
1. Skin injury
Blood vessels in the dermis become damaged when the skin is broken which results in bleeding at the site of the injury.



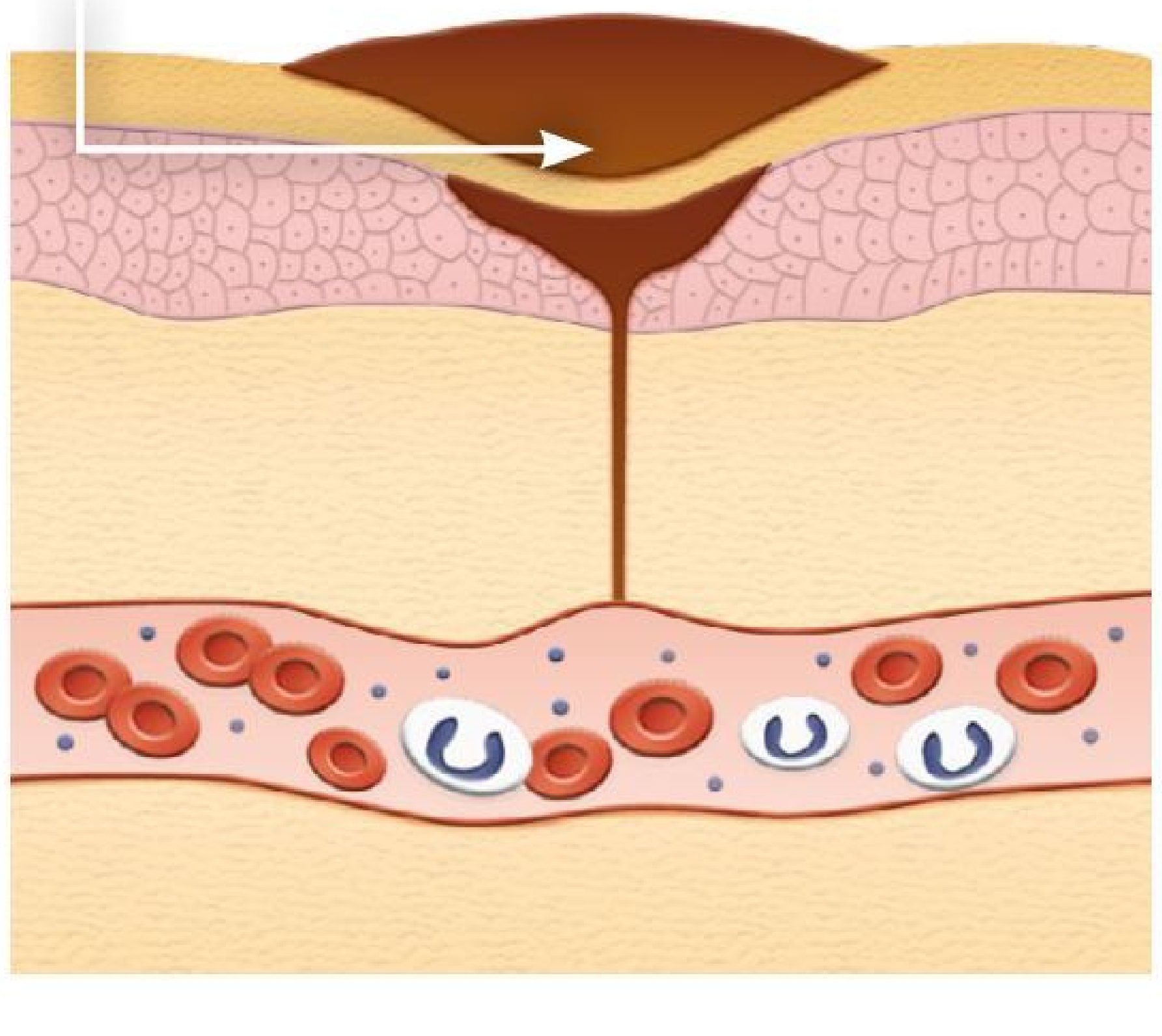
2. Clotting
The body's repair cells, which include fibroblasts, travel towards the injury site and the blood forms a clot.

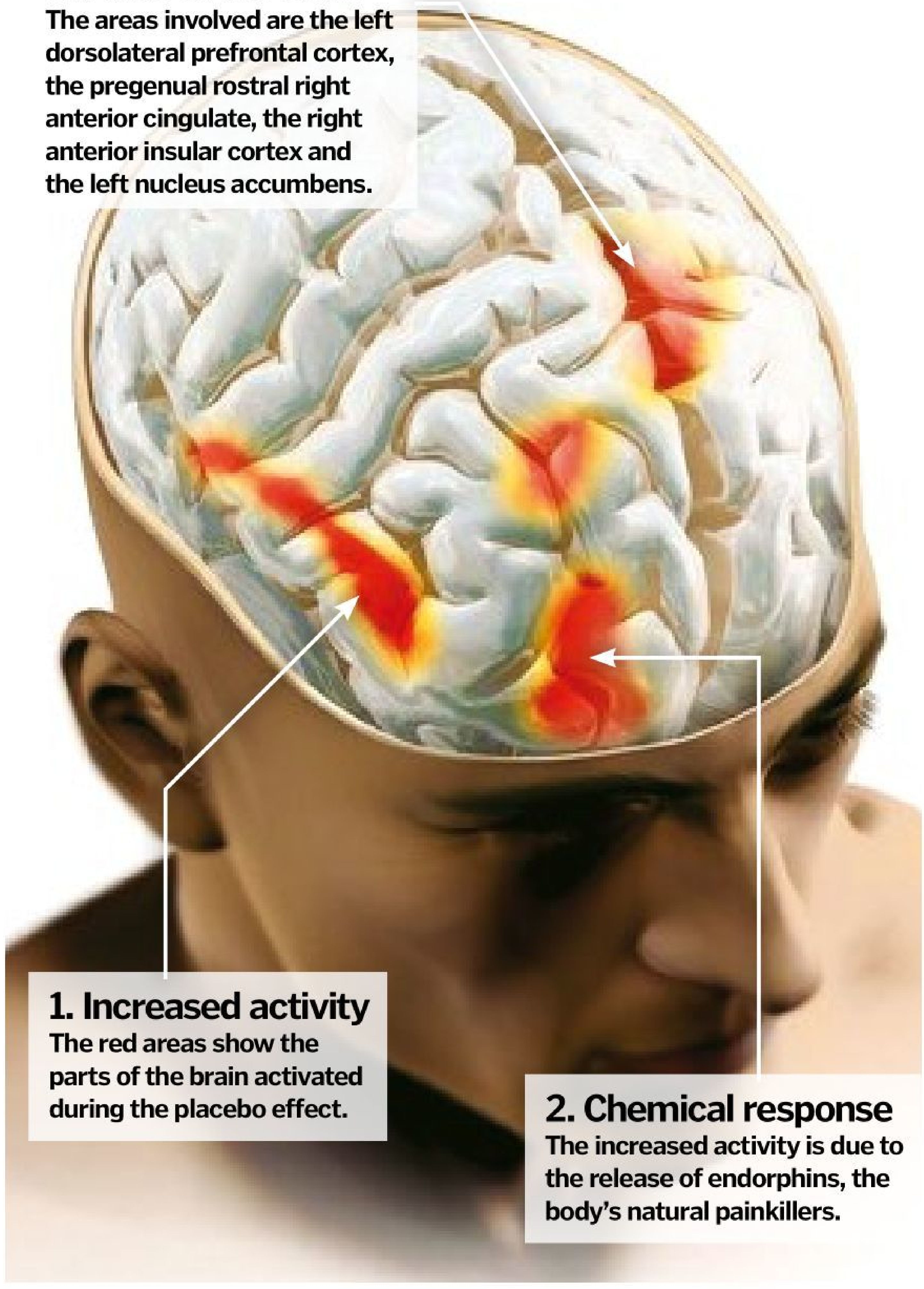


3. Plugging
A plug of fibrous tissue is formed within the clot by the fibroblasts. This allows new tissue to form beneath the protection of the plug.



4. Scab
A scab is formed by the fibrous plug hardening. It will eventually fall off but may leave some scarring at the location of the wound.





3. Parts of the brain
The areas involved are the left dorsolateral prefrontal cortex, the pregenual rostral right anterior cingulate, the right anterior insular cortex and the left nucleus accumbens.

1. Increased activity
The red areas show the parts of the brain activated during the placebo effect.

2. Chemical response
The increased activity is due to the release of endorphins, the body's natural painkillers.

Placebos – do they work?

What are placebos, how do they actually work, and can they really cure disease?

The placebo effect occurs when a patient with a condition responds positively to a treatment that doesn't have any medical value. It is thought to alleviate conditions due to the patient believing they are being treated, and psychologically they start to feel better.

It is thought that the improvements often seen with placebos might be due to conditioned responses (for example, taking medicines makes you feel better, therefore you feel better because you're taking medicine). However, sceptics commonly state that the so-called placebo effect is actually only seen because patients want to please the doctors or testers, and that in truth placebos have no effect at all.

Ultimately, placebos will not cure physical conditions – they can only affect the individual's mental state, which may be seen to then aid physical and mental recovery. With some patients and some illnesses, a placebo is potentially a very powerful mental and psychological tool for use in a number of cases, but often is not a valid replacement for treatment.

The kidneys are the body's natural filters. You can survive on just one, but when that fails you may need a transplant

Kidney transplants

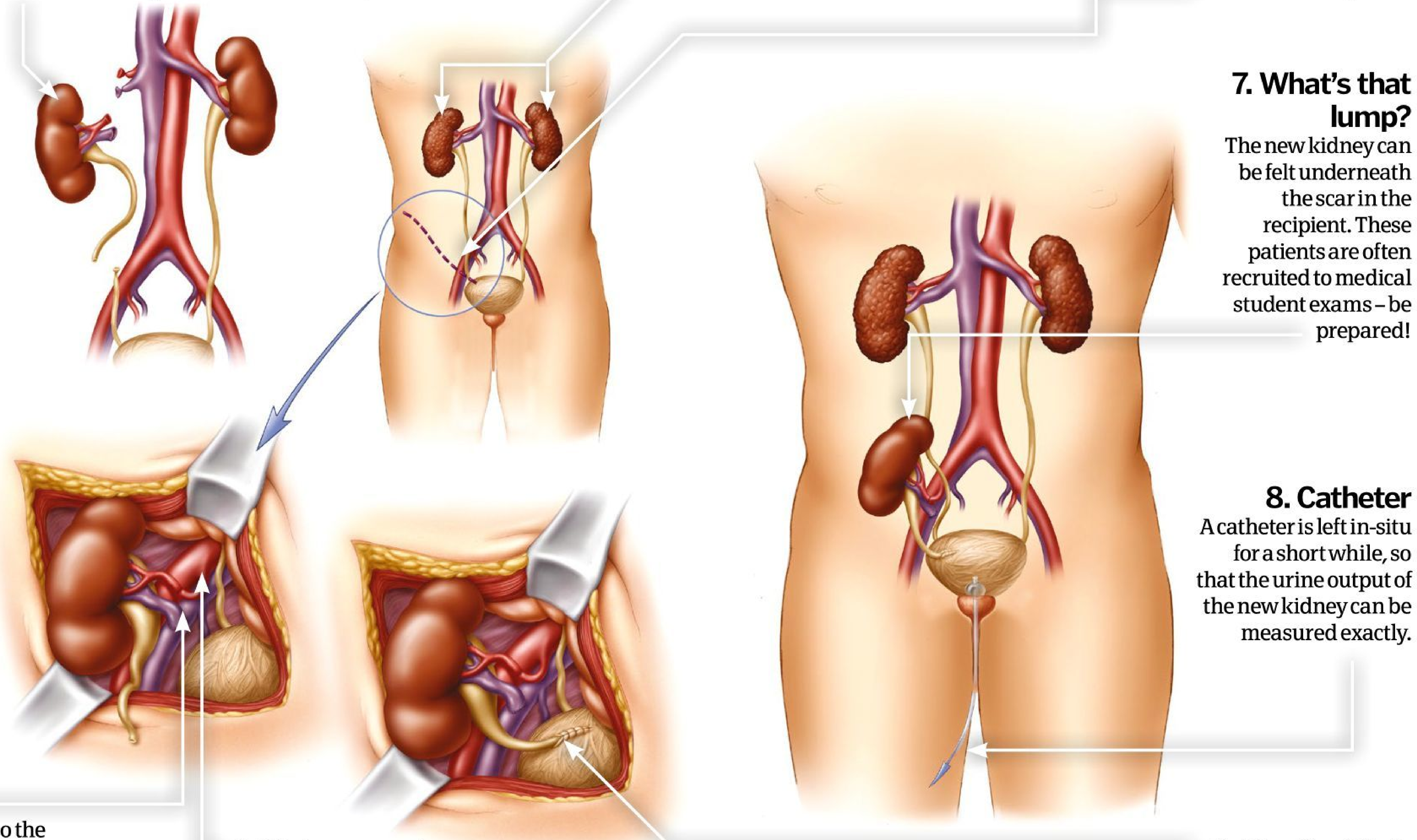
Transplanting organs is a complex process, although it can give a new lease of life to recipients. The kidney is the most frequently transplanted organ, both in the UK and around the world. However, there is a discrepancy between the number of patients waiting for a transplant and the number of available organs; only around one third of those waiting per year receive their transplant. The number of patients registered for a kidney transplant increases each year, and has risen by 50 per cent since 2000.

Kidney transplants come from two main sources: the living and the recently deceased. If a healthy, compatible family member is willing to donate a kidney, they can survive with just one remaining kidney. In other cases, someone else's tragedy is another person's fortune. For those who are declared brain-dead, the beating heart will keep the kidneys perfused until they are ready to be removed. In some patients, the ventilator will be switched off and it's a race against time to harvest organs. Either way, consent from the family is needed, even at such an emotional and pressurised time.

When a suitable organ becomes available, it is matched via a national register to a suitable recipient. A 'retrieval' team from a central transplant unit (of which there are 20 based around the UK) will go to whichever hospital the donor is in. They will remove the organs, while the recipient is being prepared in the base hospital. During the tricky operation, the new kidney is 'plumbed' into the pelvis, leaving the old, non-functioning ones in-situ.

How to perform a kidney transplant

Transplanting a kidney is a case of careful and clever plumbing. The first step is to harvest the donor kidney, and then it's a dash to transplant the new kidney into the recipient. When the brain-dead donor is transferred to the operating theatre for organ harvest, they are treated with the same care and respect as if they were still alive. When consent has been given for multiple organ harvest, a cut is made from the top of the chest to the bottom of the pelvis. The heart and lungs are retrieved first, followed by the abdominal organs.



1. The donor
The donor kidney is harvested, including enough length of artery, vein and ureter (which carries urine to the bladder) to allow tension-free implantation into the recipient.

2. Out with the old?
As long as there's no question of cancer, the original kidneys are left in place.

3. Into the pelvis
An incision is made in the lower part of the abdomen to gain access into the pelvis.

7. What's that lump?
The new kidney can be felt underneath the scar in the recipient. These patients are often recruited to medical student exams – be prepared!

8. Catheter
A catheter is left in-situ for a short while, so that the urine output of the new kidney can be measured exactly.

5. Plumbing it in
The renal artery and vein are connected to the corresponding iliac artery and vein in the recipient's body. Holes (arteriotomies) are created in the main arteries, and the kidney's vessels are anastomosed (a surgical join between two tubes using sutures).

4. Make space!
The surgeon will create space in the pelvis, and identify the large vessels which run from the heart to the leg (the iliac arteries and veins). The new kidney's vessels will be connected to these.

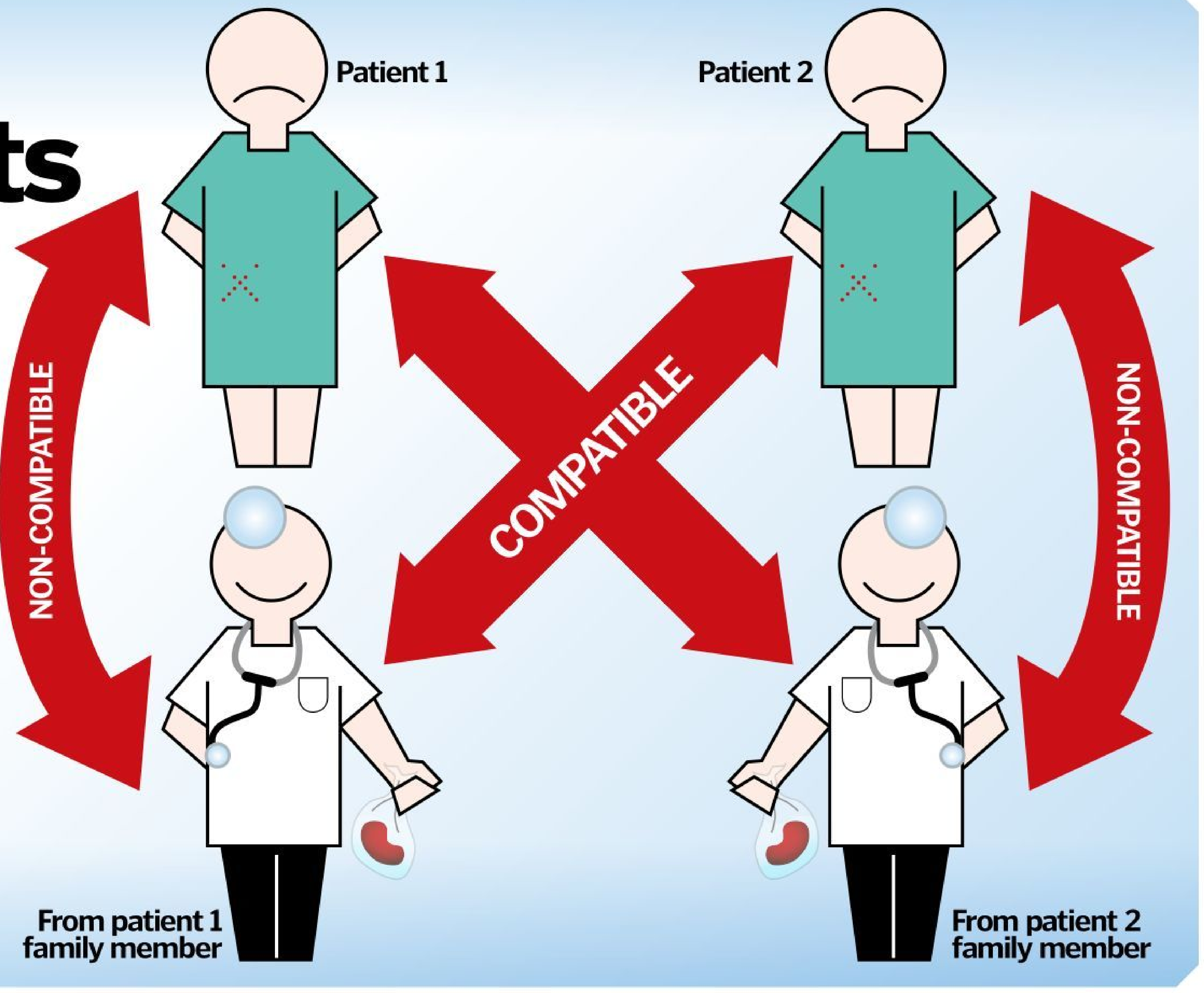
6. The final link
The ureter, which drains urine from the kidney, is connected to the bladder. This allows the kidney to function in the same way as one of the original kidneys.

© Science Photo Library

DID YOU KNOW? *Of the millions of people in the UK suffering from kidney disease, 50,000 will suffer end-stage renal failure*

Domino transplants

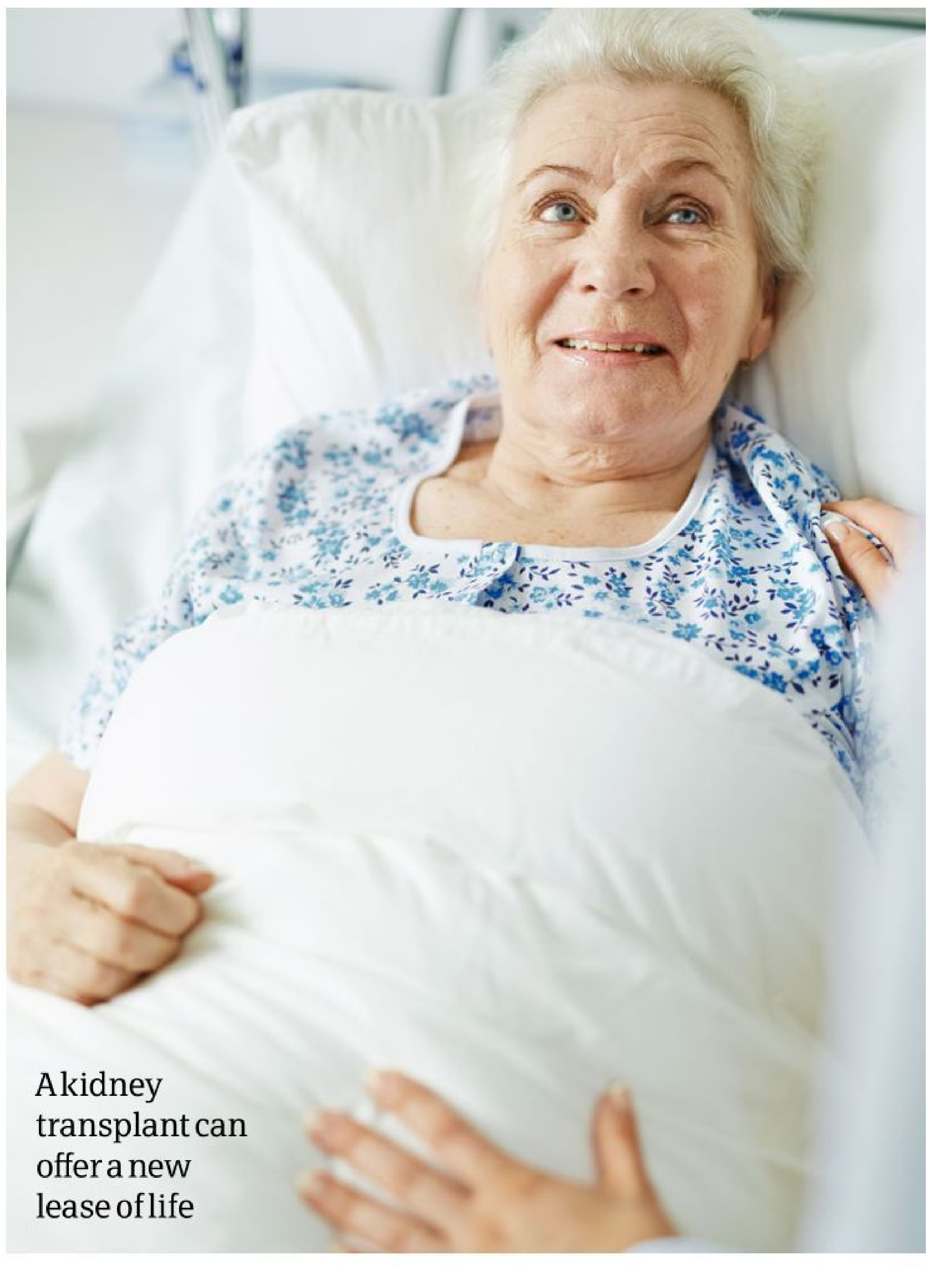
Patient 1 needs a new kidney but their family member isn't compatible. Patient 2 also needs a kidney and has an incompatible family member as well. However, patient 2's relation is compatible with patient 1 and vice versa. The surgeon arranges a swap – a 'paired' transplant. A longer line of patients and family members swapping compatible kidneys can be arranged – a 'daisy-chain' transplant. A 'good Samaritan' donor, who isn't related to any of the recipients, can start the process. This first recipient's family member will subsequently donate to someone else – a 'domino' transplant effect which can go on for several cycles.



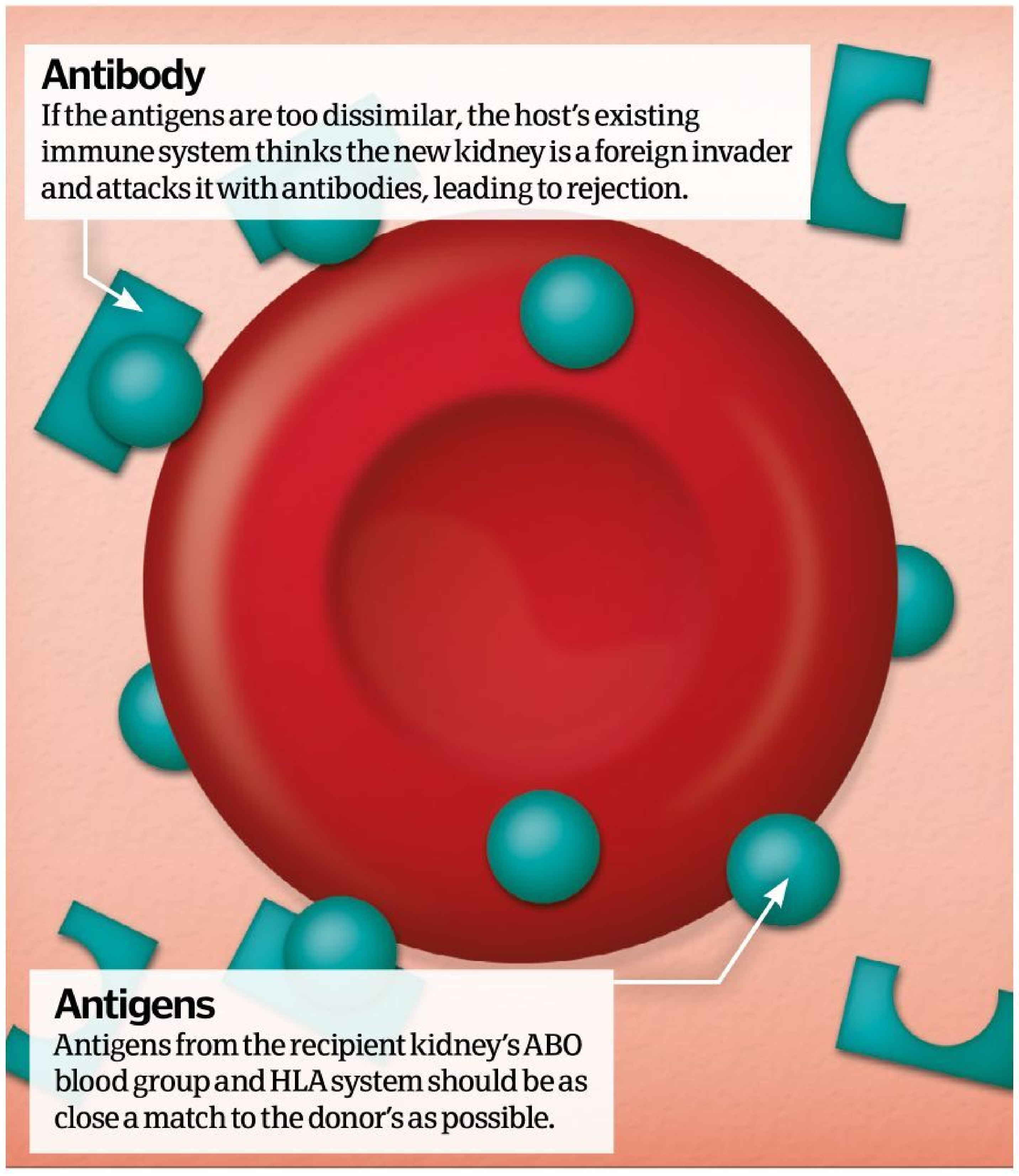
Who is suitable?

Of the several million people in the UK with kidney disease, only around 50,000 will develop end-stage renal failure (ESRF). For these people, dialysis or kidney transplantation are the only options. Kidney damage from diabetes is the most common cause of transplantation. Other causes include damage from high blood pressure, chronic kidney scarring (chronic pyelonephritis) and polycystic kidney disease (the normal kidney tissue is replaced with multiple cysts); many other less common causes exist.

Patients must be selected carefully due to the scarcity of organs. Those with widespread cancer, severely calcified arteries, persistent substance abuse and unstable mental problems mean that transplants are likely to fail and so these patients are unsuitable to receive a precious kidney transplant.



A kidney transplant can offer a new lease of life



Antibody
If the antigens are too dissimilar, the host's existing immune system thinks the new kidney is a foreign invader and attacks it with antibodies, leading to rejection.

Antigens
Antigens from the recipient kidney's ABO blood group and HLA system should be as close a match to the donor's as possible.

When things go wrong…

Kidneys need to be carefully matched to suitable donors, or rejection of the new organ will set in fast. Rejection occurs when the host body's natural antibodies think the new tissue is a foreign invader and attacks; careful pre-operative matching helps limit the degree of this attack. The most important match is via the ABO blood group type – the blood group must match or rejection is fast and aggressive. Next, the body's HLA (human leukocyte antigen) system should be as close a match as possible, although it doesn't need to be perfect. Incorrect matches here can lead to rejection over longer periods of time. After the operation, patients are started on anti-rejection medicines which suppress the host's immune system (immunosuppressants such as Tacrolimus, Azathioprine or Prednisolone). Patients are monitored for the rest of their lives for signs of rejection. These immunosuppressants aren't without their risks – since they suppress the body's natural defences, the risks of infections and cancers are higher.

Time is always of the essence

© Science Photo Library

Pack carefully!

The transport of harvested organs is time critical – the sooner the surgeon can put them into the recipient the better. As soon as blood stops flowing to the harvested tissue, the lack of oxygen damages these cells, which is called ischaemia. The retrieval team have a few tricks up their sleeves to maximise the viability of the precious cargo they carry.

In the operating theatre, just before they remove the harvested kidney, it is flushed clean of blood with a special cold, nutrient-rich solution. Once removed, it is quickly put in a sterile container with ice. The most modern technique is to use a cold perfusion machine instead of ice, which pumps a cooled solution through the kidney and improves its lasting power. While hearts and lungs can only last around four hours, kidneys can last 24-48 hours. Transfer of the affected organ is done via the fastest method possible; this often involves using helicopters or police escorts.

All of these methods prolong the preservation time of the kidney, although once 'plugged' back in, it can take a few days for the kidney to start working properly (especially if harvested from a non-heart-beating donor).

How cloning works

From Dolly the sheep to stem cell farms, we explore the myths and reality of cloning

Inside the nucleus of every living cell is DNA, the genetic blueprint that makes each living creature unique. In rare cases, a fertilised egg will divide and separate inside the womb, forming two embryos with the same DNA. The resulting identical twins, which make up a scant 0.2 per cent of the world's population, are nature's perfect clones.

When we think of artificial cloning, most of us tend to fall back on bad science-fiction movies where teams of evil scientists replicate humans with giant photocopiers or grow armies of clone babies in glass-walled tanks. The reality of artificial cloning is much closer to Mother Nature's model.

When scientists set out to artificially (or asexually) clone an organism, they take their cues from natural (or sexual) reproduction. In sexual reproduction, the sperm and egg cells each carry a single set of chromosomes containing exactly half of each parent's genes. When the sperm fertilises the egg, the two halves of the genetic map combine to form a full set of chromosomes that is unique from either parent.

A fertilised egg is called a zygote. As the zygote divides and develops into an embryo, the same copy of DNA is passed along to every cell in the organism, whether it's a liver cell, eye cell or brain cell. The cells ultimately look and behave differently because different genes along the DNA strand are expressed to perform different cell functions.

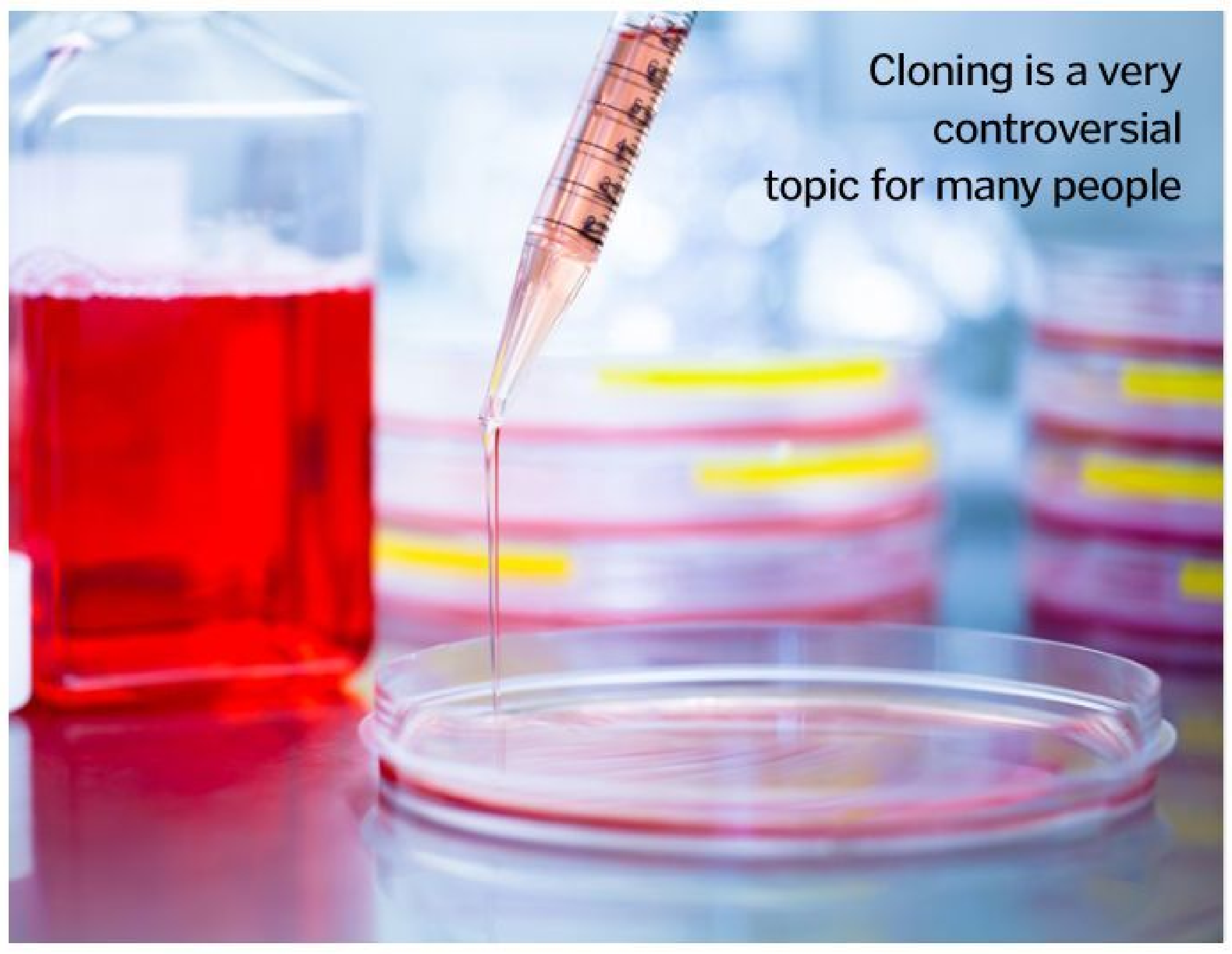
The earliest artificial cloning efforts in the late-1970s were quite basic. In a procedure called artificial embryo twinning, scientists mimicked the natural twinning process by physically dividing an early embryo into individual cells that had yet to specialise. After a day or two in a Petri dish, the developing identical embryos were implanted into a surrogate mother and brought to term.

But the most effective artificial cloning method to date – the one that brought us Dolly the sheep in 1996 – is called somatic cell nuclear transfer. Somatic cells are 'body' cells like skin or liver cells that carry a full copy of DNA. To create a clone using this method, scientists extract the nucleus of an adult somatic cell and insert it into an 'enucleated' egg cell from a second animal, ie an egg whose nucleus and original genetic material has been destroyed or removed. Lab technicians execute these manoeuvres with pipette needles 2/10,000th of an inch wide.

Scientists then use a precision jolt of electricity or a chemical trigger to stimulate cell division in the transplanted egg. Instead of generating more specialised somatic cells – as you might expect DNA from an 'adult' cell to do – the transplanted DNA reboots to its original orders and starts to create an embryo. The resulting foetus, implanted into a surrogate mother, grows to become an exact genetic clone of the animal that donated the somatic cell.

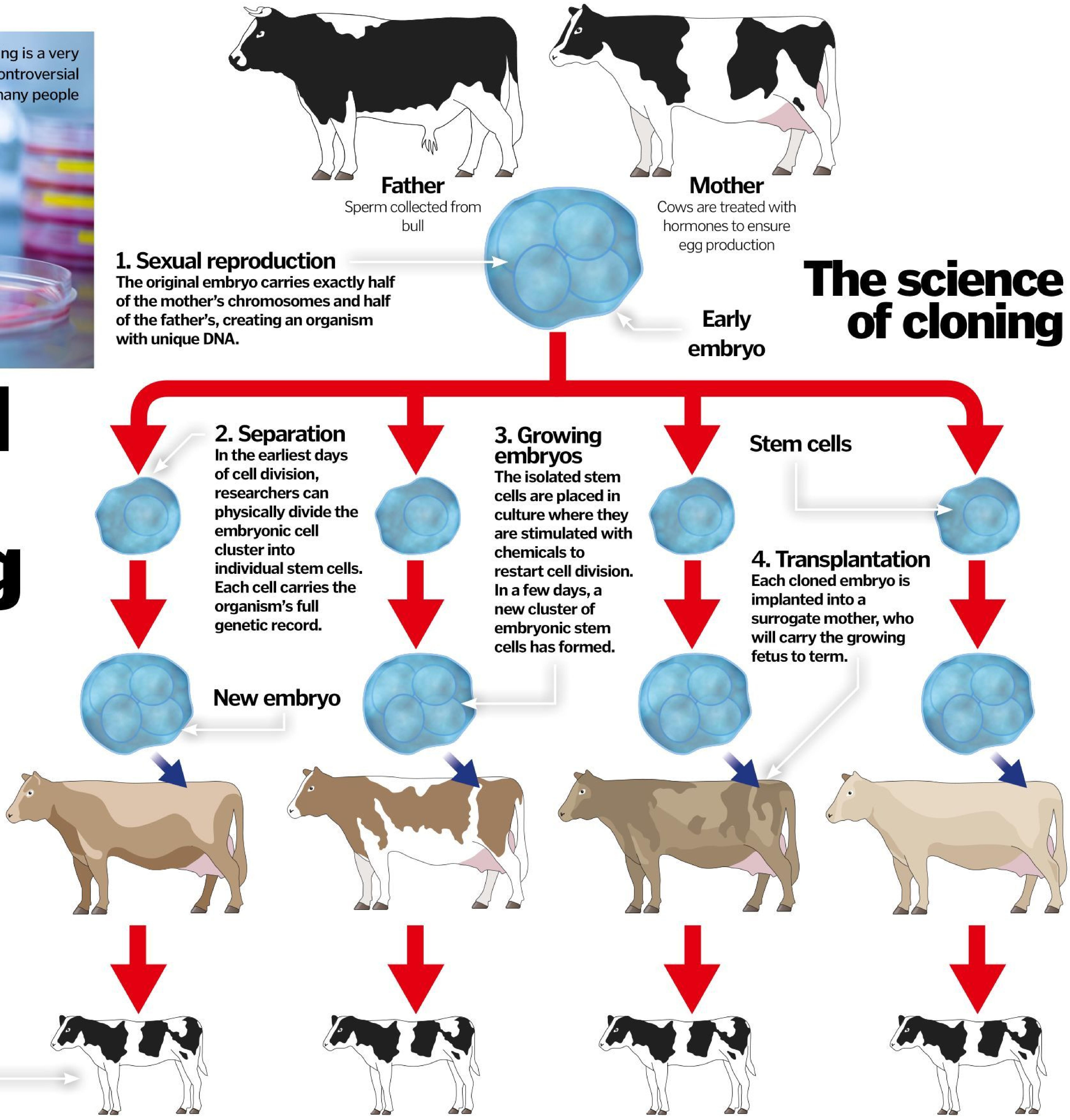
Somatic cell transfer is often used for reproductive cloning – making copies of organisms with highly desirable genetic traits. For example, the same researchers who cloned

DID YOU KNOW? *The success rate of cloning by somatic cell nuclear transfer is only between one and four per cent*


Cloning is a very controversial topic for many people

Artificial embryo twinning

Identical twins are a fluke. When the fertilised egg is only days old, it spontaneously and inexplicably splits into two equal clusters of stem cells, each carrying the exact same genetic blueprint. Researchers can mimic this process in the lab by physically separating individual stem cells during the earliest moments of cell division and implanting the identical embryos into surrogate mothers.


The science of cloning

Father
Sperm collected from bull

Mother
Cows are treated with hormones to ensure egg production

1. Sexual reproduction
The original embryo carries exactly half of the mother's chromosomes and half of the father's, creating an organism with unique DNA.

Early embryo

2. Separation
In the earliest days of cell division, researchers can physically divide the embryonic cell cluster into individual stem cells. Each cell carries the organism's full genetic record.

3. Growing embryos
The isolated stem cells are placed in culture where they are stimulated with chemicals to restart cell division. In a few days, a new cluster of embryonic stem cells has formed.

Stem cells

4. Transplantation
Each cloned embryo is implanted into a surrogate mother, who will carry the growing fetus to term.

New embryo

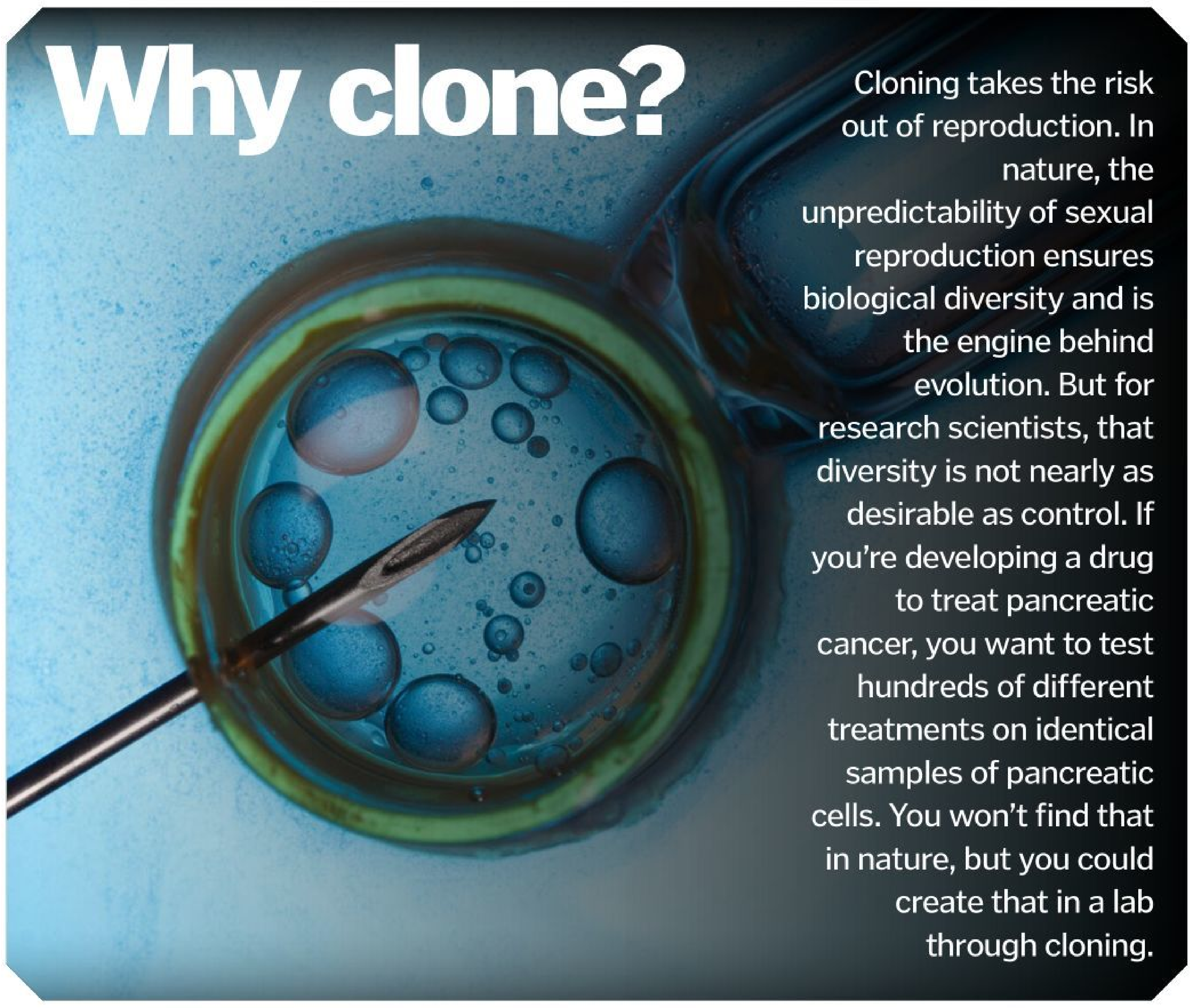
5. Herd of clones
The genetic makeup of the surrogate mothers has no effect on the offspring. Each calf carries the same exact combination of the original parents' DNA, resulting in identical physical traits.

Dolly have also cloned a genetically modified sheep named Polly whose milk contains a protein that aids blood clotting in haemophiliacs. By producing thousands of clones of Polly, scientists can isolate more and more of the protein to manufacture blood-clotting drugs.

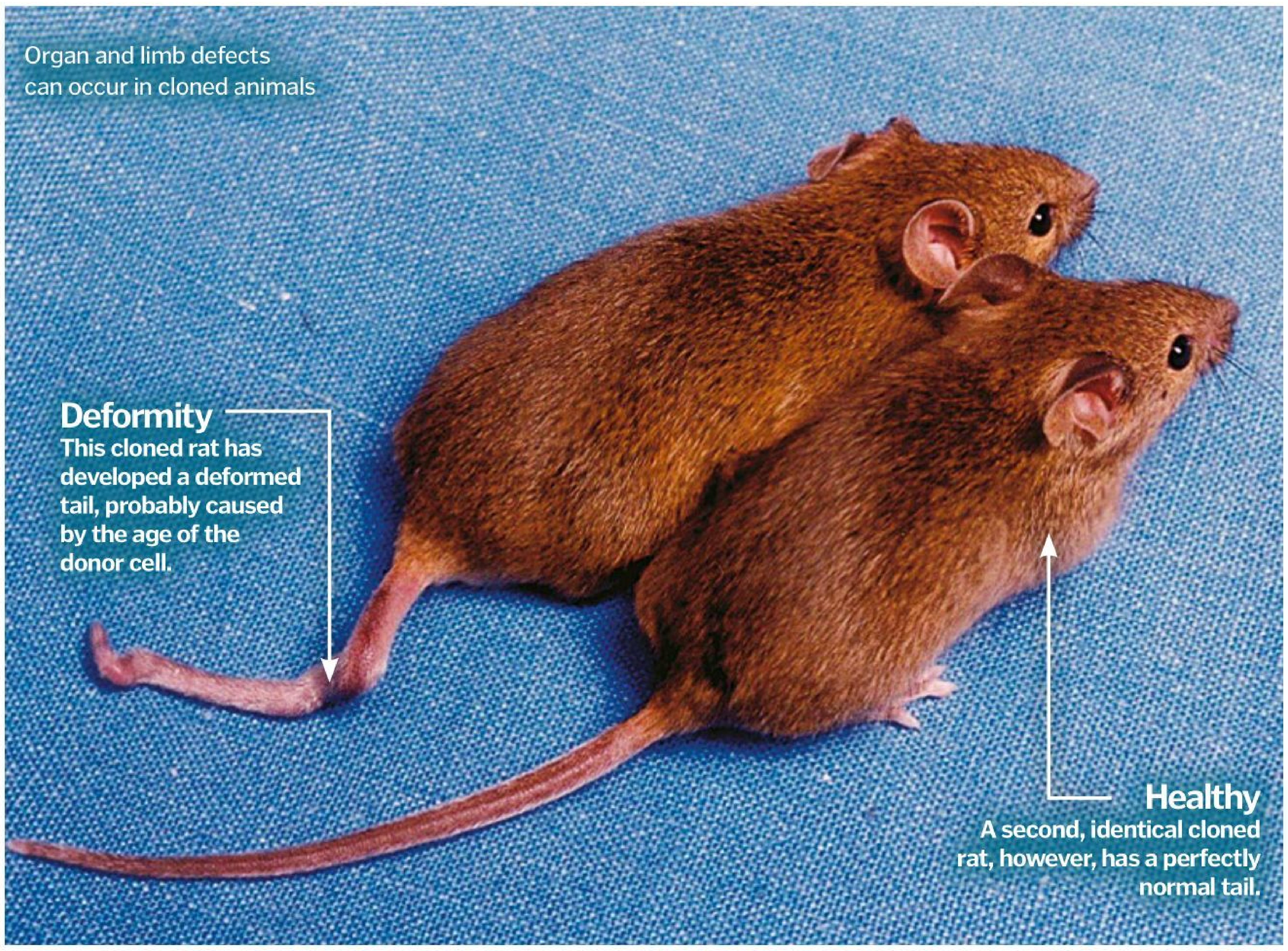
Cattle, sheep, pigs and other animals have been bred by farmers for millennia to produce leaner, protein-rich meat and more flavourful milk. But conventional breeding still allows for a genetic roll of the dice, which can occasionally result in small, sickly offspring. Successful reproductive cloning, some say, would ensure a steady supply of only the fittest and healthiest animals.

In 2008, the US Food and Drug Administration approved the sale of foods containing milk and meat from cloned animals, although the prohibitive cost of cloning has kept cloned food off the shelves so far. The European Union has made no such approvals, although breeders throughout Europe are already using imported semen and embryos from cloned animals bred in the US.

Scientists have also used reproductive cloning to bring endangered species back from the brink of extinction. In 2001, researchers used somatic cell nuclear transfer to clone an endangered gaur ox. Unfortunately, the animal died soon after birth from an infection. Since then,


Why clone?

Cloning takes the risk out of reproduction. In nature, the unpredictability of sexual reproduction ensures biological diversity and is the engine behind evolution. But for research scientists, that diversity is not nearly as desirable as control. If you're developing a drug to treat pancreatic cancer, you want to test hundreds of different treatments on identical samples of pancreatic cells. You won't find that in nature, but you could create that in a lab through cloning.



Organ and limb defects can occur in cloned animals

Deformity This cloned rat has developed a deformed tail, probably caused by the age of the donor cell.

Healthy A second, identical cloned rat, however, has a perfectly normal tail.

© Emma Whitelaw, University of Sydney, Australia

another ox and three African wildcats have been successfully cloned to repopulate their species.

The first cloned cat was born in 2001 and a firm in South Korea produced the first cloned canine in 2005. Since then, passionate pet owners have paid as much as £600 a year to preserve their beloved cat or dog's tissue for post-mortem cloning, a process that runs to nearly £100,000.

Not all cloning experiments have been for the sake of reproduction, though. With therapeutic cloning, the goal of researchers is to isolate and replicate stem cells in order to study their potentially life-saving applications. Stem cells are undifferentiated cells that carry a full copy of an organism's DNA, but have yet to express any of their genes as skin cells, bone cells, sperm cells or any other adult cell. Researchers can program stem cells to grow specific organ tissue, like healthy brain cells to treat Alzheimer's sufferers or replacement bone marrow cells for cancer patients.

Therapeutic cloning also relies on the somatic cell nuclear transfer method. In 2007, researchers harvested stem cells from cloned rhesus monkey embryos. It takes about five days for a cloned embryo to reach the blastocyst phase, when the total cell count has grown to around 100. At this size, stem cells can be extracted and placed in a nutrient-rich culture medium where they grow into complete stem cell 'lines'.

Dolly the sheep

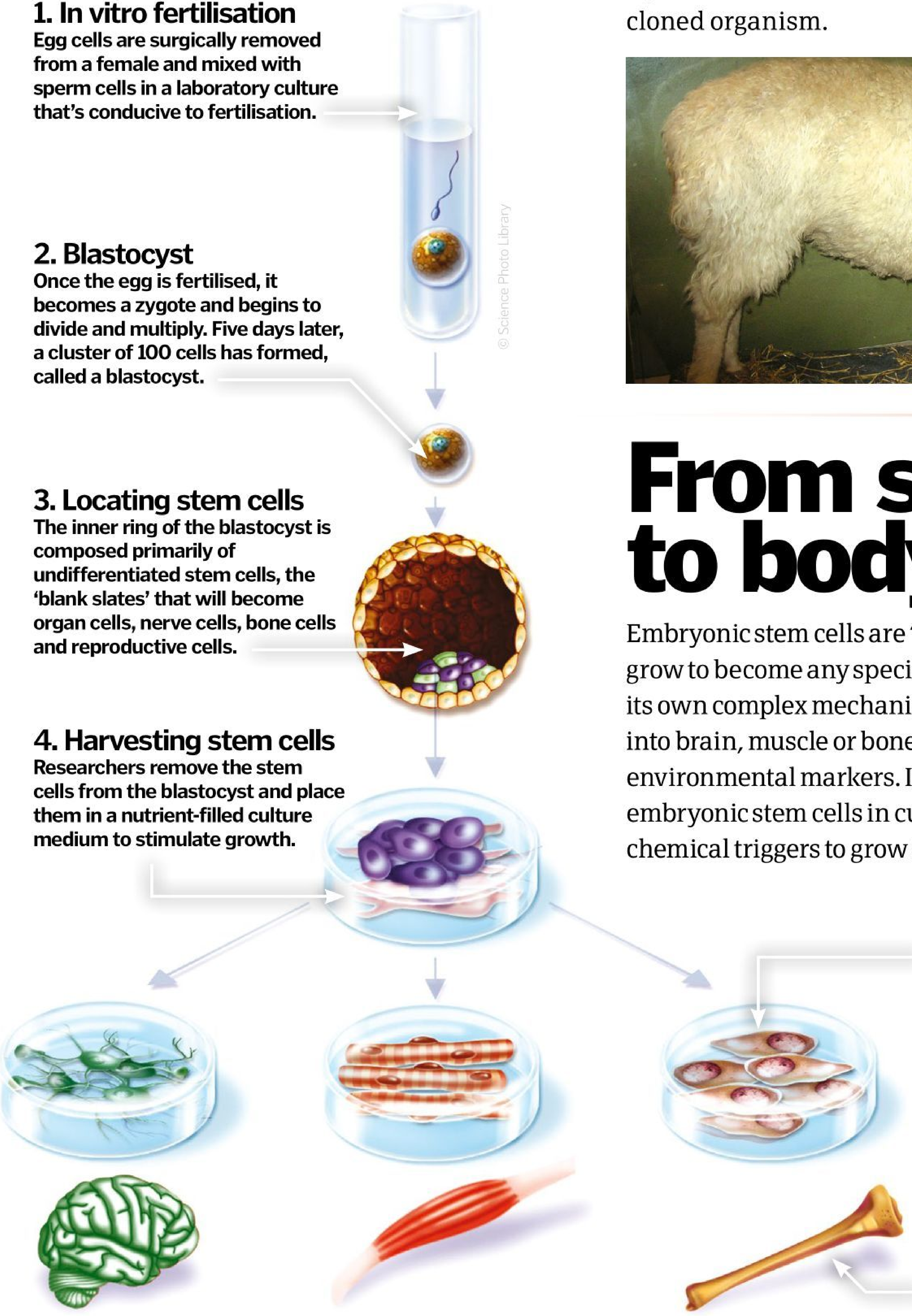
A remarkable breakthrough that changed the world of cloning

Dolly the sheep was the celebrity of the cloning world. Back in 1996, after 276 failed attempts, researchers at the Roslin Institute in Scotland became the first scientists to successfully clone a mammal. The method was somatic cell nuclear transfer, in which the nucleus of an egg cell is sucked out and replaced with the nucleus of a normal body cell (or 'somatic' cell) from an adult sheep. Using electrical impulses, the egg is induced to divide, growing into an embryo that shares the identical genetic material as the somatic cell donor. This requires sensitive manipulations of cellular material at the microscopic level, explaining the low success rate. Dolly's life in the spotlight was relatively short-lived and she died at age six. One drawback of somatic nuclear transfer is that the age of the donor cell seems to affect the longevity of the cloned organism.

Dolly – the most famous sheep in the world

From stem cell to body part

Embryonic stem cells are 'pluripotent', meaning they can grow to become any specialised cell in the body. Nature has its own complex mechanisms for differentiating stem cells into brain, muscle or bone, involving both genetic and environmental markers. In the lab, researchers can isolate embryonic stem cells in culture and provide the right chemical triggers to grow fresh skin cells and even organs.



© Science Photo Library

1. In vitro fertilisation
Egg cells are surgically removed from a female and mixed with sperm cells in a laboratory culture that's conducive to fertilisation.

2. Blastocyst
Once the egg is fertilised, it becomes a zygote and begins to divide and multiply. Five days later, a cluster of 100 cells has formed, called a blastocyst.

3. Locating stem cells
The inner ring of the blastocyst is composed primarily of undifferentiated stem cells, the 'blank slates' that will become organ cells, nerve cells, bone cells and reproductive cells.

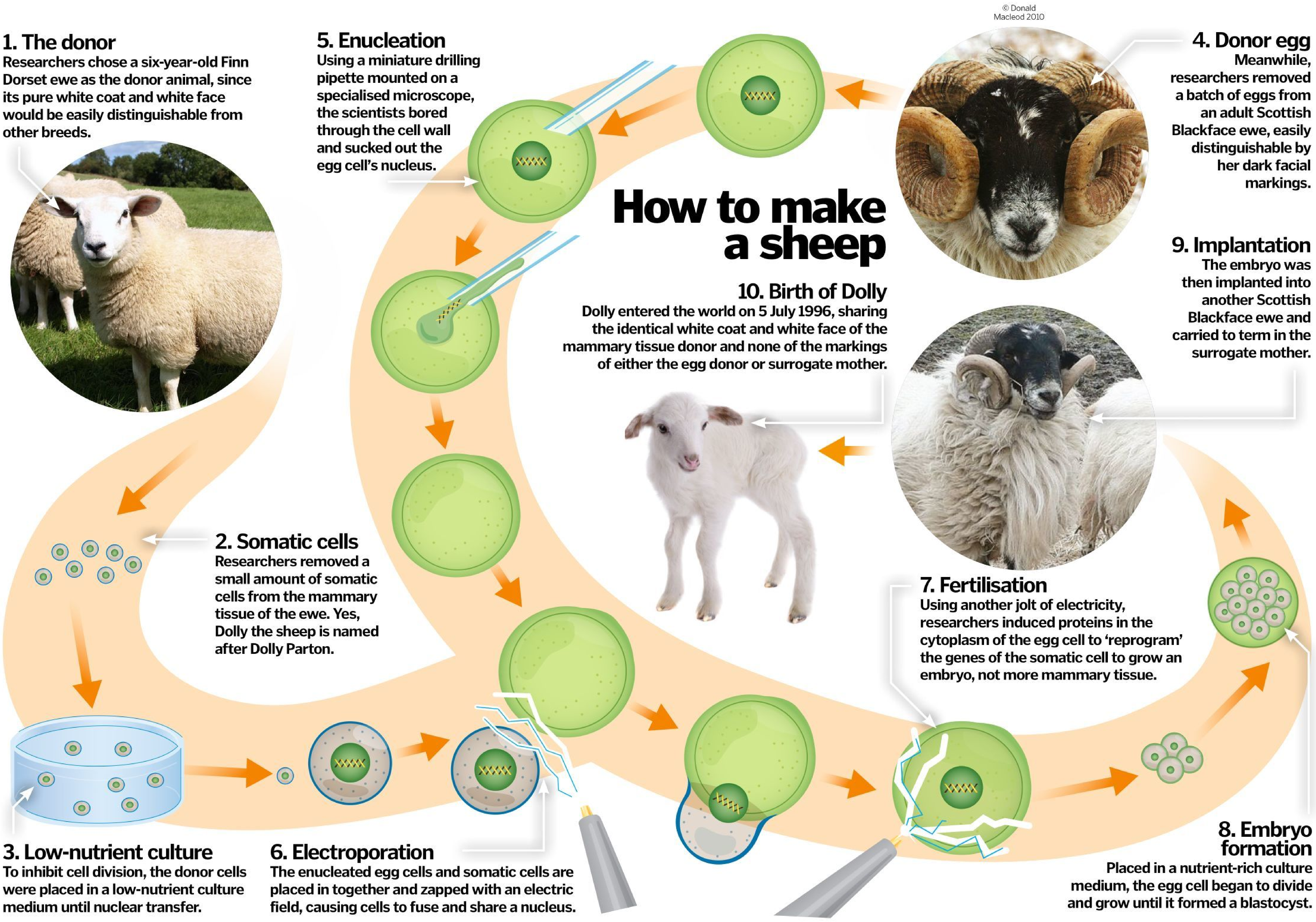
4. Harvesting stem cells
Researchers remove the stem cells from the blastocyst and place them in a nutrient-filled culture medium to stimulate growth.

5. Differentiation
Batches of stem cells are transferred to other culture dishes where they are stimulated with chemicals, and even segments of genes to grow into specialised cells.

6. Organ formation
In recent years, researchers have found success growing bladder and skin cells on prefab scaffolds that mould the cells into the shape of the desired body part.

DID YOU KNOW? *Cloned animals don't always look identical. The first cloned cat had a different coloured coat than its match*

How to make a sheep


© Donald Macleod 2010

1. The donor
Researchers chose a six-year-old Finn Dorset ewe as the donor animal, since its pure white coat and white face would be easily distinguishable from other breeds.

2. Somatic cells
Researchers removed a small amount of somatic cells from the mammary tissue of the ewe. Yes, Dolly the sheep is named after Dolly Parton.

3. Low-nutrient culture
To inhibit cell division, the donor cells were placed in a low-nutrient culture medium until nuclear transfer.

4. Donor egg
Meanwhile, researchers removed a batch of eggs from an adult Scottish Blackface ewe, easily distinguishable by her dark facial markings.

5. Enucleation
Using a miniature drilling pipette mounted on a specialised microscope, the scientists bored through the cell wall and sucked out the egg cell's nucleus.

6. Electroporation
The enucleated egg cells and somatic cells are placed in together and zapped with an electric field, causing cells to fuse and share a nucleus.

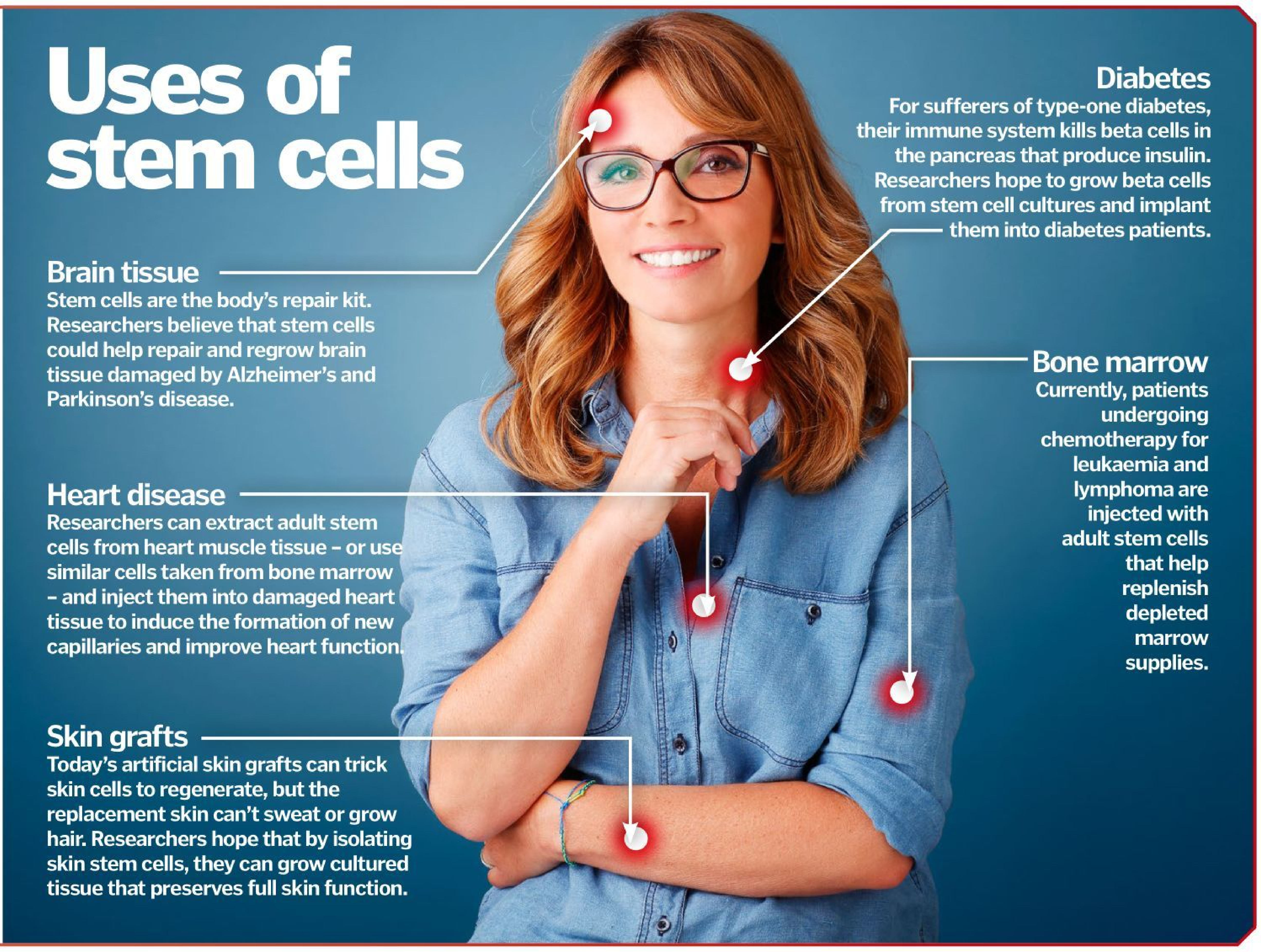
7. Fertilisation
Using another jolt of electricity, researchers induced proteins in the cytoplasm of the egg cell to 'reprogram' the genes of the somatic cell to grow an embryo, not more mammary tissue.

8. Embryo formation
Placed in a nutrient-rich culture medium, the egg cell began to divide and grow until it formed a blastocyst.

9. Implantation
The embryo was then implanted into another Scottish Blackface ewe and carried to term in the surrogate mother.

10. Birth of Dolly
Dolly entered the world on 5 July 1996, sharing the identical white coat and white face of the mammary tissue donor and none of the markings of either the egg donor or surrogate mother.

Uses of stem cells



Brain tissue
Stem cells are the body's repair kit. Researchers believe that stem cells could help repair and regrow brain tissue damaged by Alzheimer's and Parkinson's disease.

Heart disease
Researchers can extract adult stem cells from heart muscle tissue – or use similar cells taken from bone marrow – and inject them into damaged heart tissue to induce the formation of new capillaries and improve heart function.

Skin grafts
Today's artificial skin grafts can trick skin cells to regenerate, but the replacement skin can't sweat or grow hair. Researchers hope that by isolating skin stem cells, they can grow cultured tissue that preserves full skin function.

Diabetes
For sufferers of type-one diabetes, their immune system kills beta cells in the pancreas that produce insulin. Researchers hope to grow beta cells from stem cell cultures and implant them into diabetes patients.

Bone marrow
Currently, patients undergoing chemotherapy for leukaemia and lymphoma are injected with adult stem cells that help replenish depleted marrow supplies.

The risks of cloning

Cloning is far from an exact science. Dolly was the 277th cloned embryo and the first to survive. But even Dolly only lived to six years old, half the average life span of her species. Several genetic abnormalities have surfaced in cloned animals, including high birth weight, organ defects and premature ageing. The culprit, many believe, is the age of the somatic donor cell. Chromosomes get shorter over time as they divide and multiply. At some point, the chromosome becomes too short to divide and the cell dies. It appears that a somatic cell's chromosomal clock is not fully reset when it's implanted into an egg, resulting in shorter life spans and sudden organ failure.

55
60
5
50
10
45
15
40
20
35
30
25

Anaesthetic makes operations much more bearable for all

© Science Photo Library

Anaesthetics

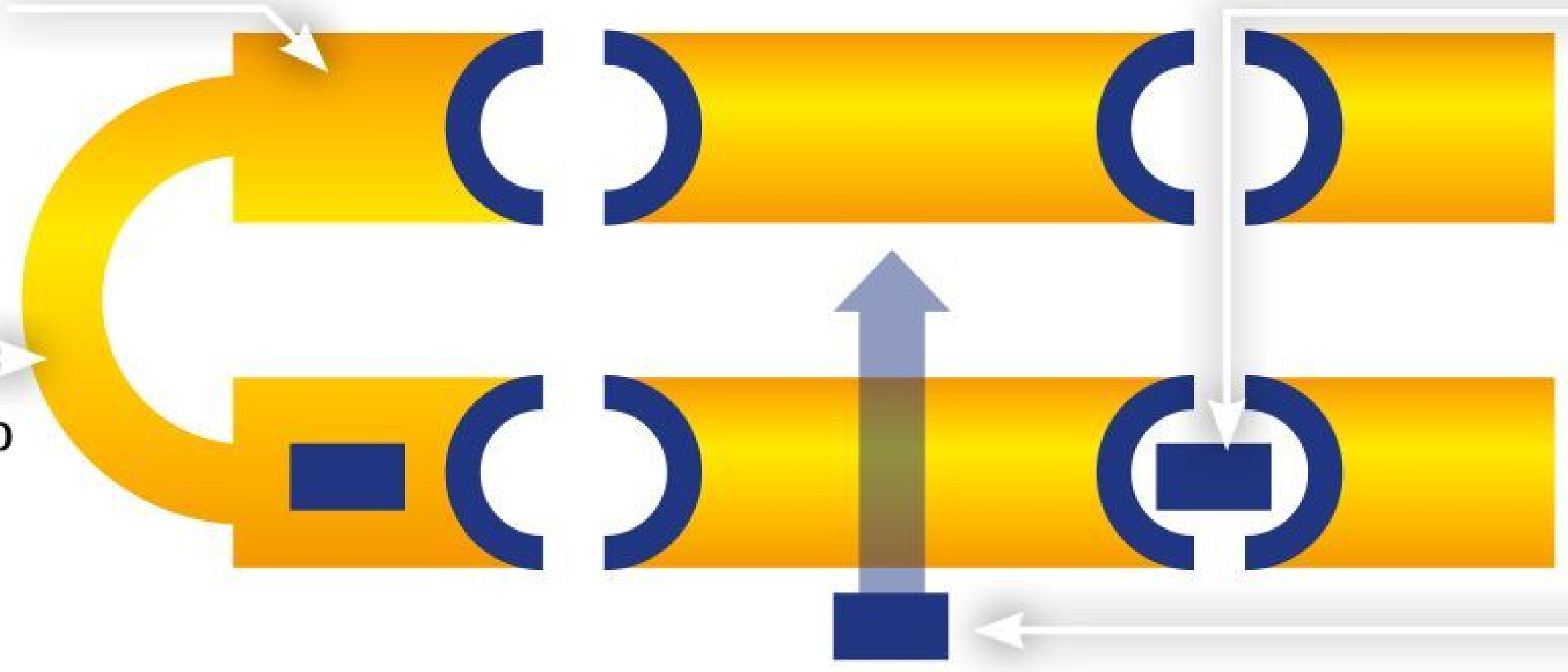
How doctors take the pain away

There are two main types of anaesthetic used to nullify pain in the body. First, there's local anaesthetic, which is used in conjunction with a sedative to limit sensation to a particular part of the body. It is usually injected, where it becomes ionised and blocks channels of sodium within the nerves transmitting information to and from the brain. These sodium channels – known as synapses – are like bridges across which signals can travel. Blocking these prevents nerves transmitting sensations of pain to the brain.

General anaesthetics work in a similar manner, again reducing nerve transmission in synapses. Commonly inhaled, they operate on the central nervous system, temporarily reducing the transmission between synapses in the nerves. The entire body becomes insensitive to pain and the patient will lose consciousness, although vital bodily functions remain active.

Numbing the pain

How anaesthetics stop nerves sending pain signals to the brain



Sodium channels
These synapses allow the transmission of the impulse which interacts with the brain.

Nerve
The nerve is connected to the cell membrane, which transmits signals to and from the brain.

Block
The ionised anaesthetic can now block the transmissions at the synapses.

Inserted
The local anaesthetic is inserted into the intended area, where it becomes ionised.

Strokes

The loss of blood supply to the brain can cause long-term damage or death

Strokes are caused when the flow of blood to the brain is interrupted. There are two main reasons why this might occur, and ischaemic strokes are the most common. They occur when a blood clot forms in an artery (thrombosis) or a blood clot forms and then travels to a brain artery (arterial embolism) that reduces or blocks the blood flow (ischemia).

The second reason is bleeding (haemorrhaging) of a blood vessel in the brain. This can be caused when a thin part of a vessel (an aneurysm) bursts. Between one and six per cent of the population have an intracranial aneurysm and every year in the United Kingdom approximately 1,400 people die of ruptured intracranial aneurysms.

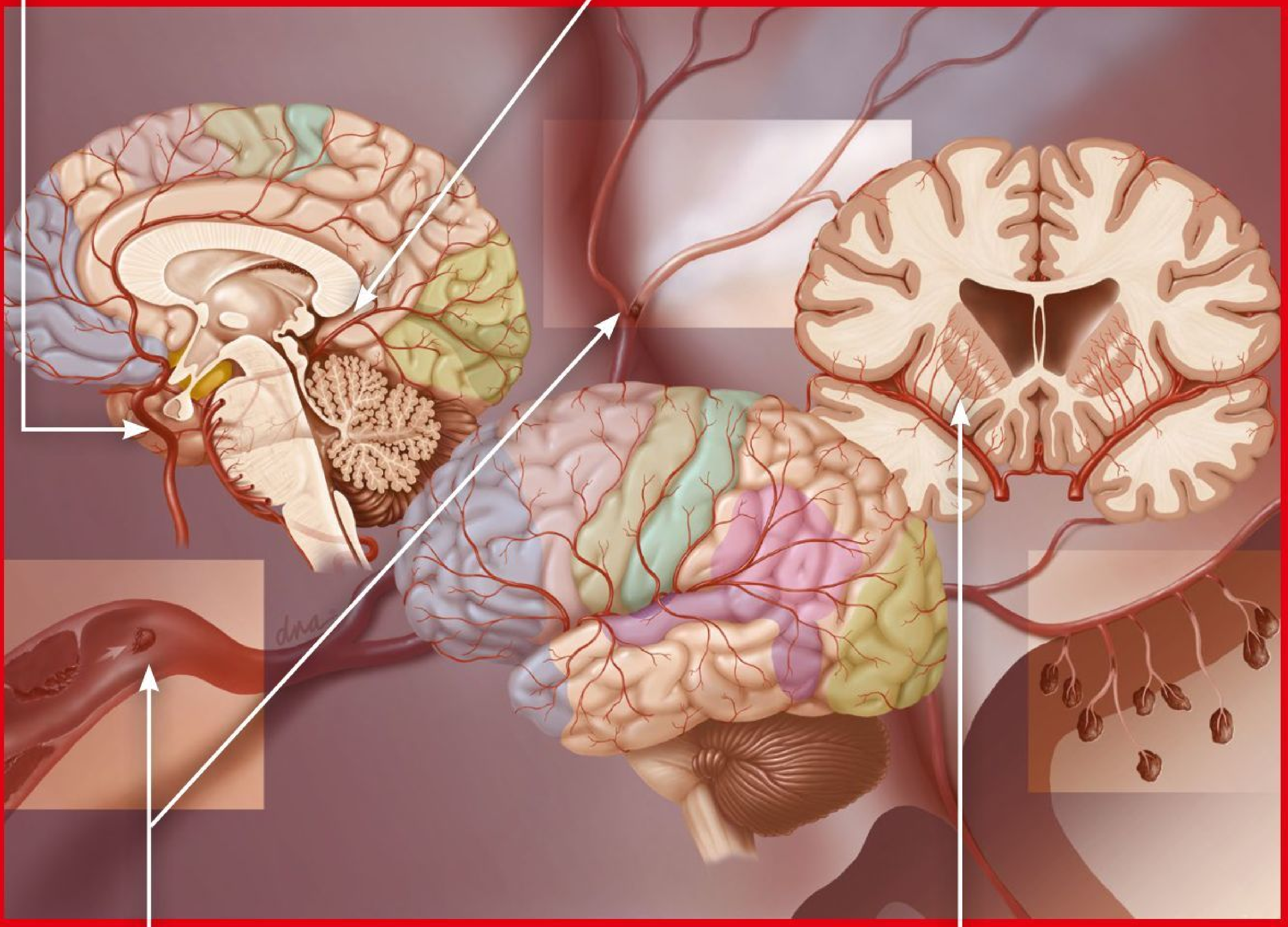
A stroke is defined when it either causes death or has a long-term effect after 24 hours. You can experience signs of a mini stroke that are called transient ischemic attacks (TIAs) that last only a few minutes or hours. The onset of a full stroke is characterised by numbness in the face and limbs. Vision can be impaired and you can have trouble walking or talking.

The effects of a stroke depend on which part of the brain was most starved of oxygen from the blood supply. In many cases, stroke victims will find it difficult to walk or eat due to muscle weakness and in extreme cases, they might experience paralysis.

Areas of impact

Carotid arteries
Carotid blood vessels, served by the internal and external carotid arteries, supply blood to the front part of the cerebrum.

Vertebral arteries
Vertebral arteries supply blood to the rest of the brain and enter the skull through the foramen magnum.



Clot
Ischaemic strokes are caused by blood clots, which can either form directly in an artery, or form and then travel to a brain artery that it then blocks, reducing blood flow.

Aneurysm
When part of a thin blood vessel bursts, haemorrhaging can occur.

DID YOU KNOW? *Rheumatoid arthritis is the second most common arthritic disease after osteoarthritis*

Rheumatoid arthritis explained

How does this condition cause intense inflammation of joints and the eventual destruction of cartilage tissue?

Rheumatoid arthritis is a chronic and progressive disease. Through inflammation throughout the connective tissues of the body, it causes irreversible damage to joints. The disease develops when a person's body generates an autoimmune response – a mistaken immune system reaction against the body's own tissues – that attacks its joint components instead of invading organisms.

As of now, scientists are unsure of what instigates the autoimmune response, but it is thought that it involves a body's genetic susceptibility to certain viruses. Regardless, once activated by such a cause, a series of immune system reactions proceed to cause unwanted/abnormal levels of inflammation and tissue/bone destruction. Inflammation is caused by a heavily abnormal interaction between B-cells and T-cells (see 'Development of the condition' boxout), a process that causes a variety of proteins, antibodies and other cells to be released which break down joint cartilage among other damaging activities.

Extreme swelling and inflammation caused by rheumatoid arthritis

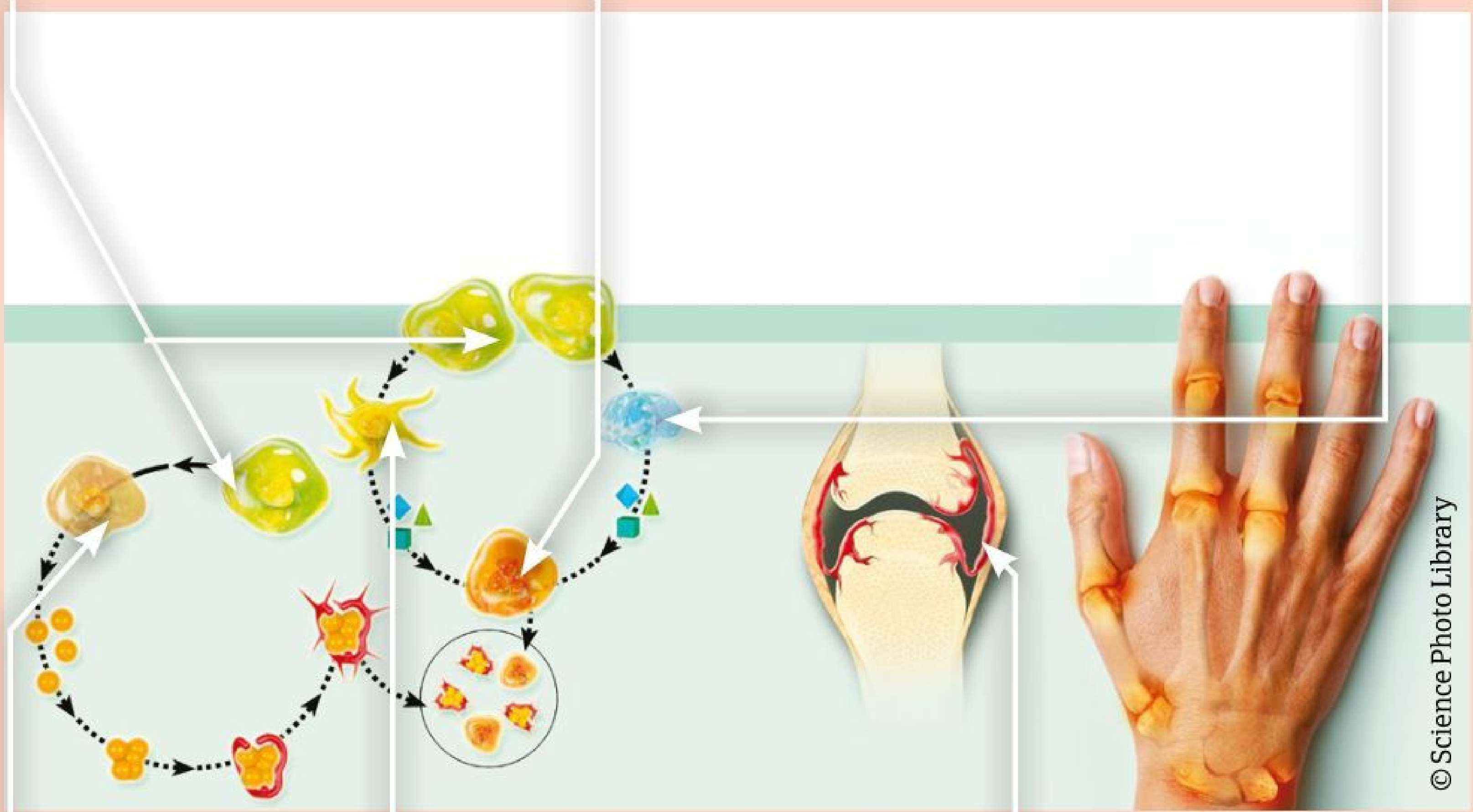
Development of the condition

The cellular mechanisms, proteins and antibodies involved in the development of rheumatoid arthritis

B-cells
B-cells are lymphocytes (white blood cells) that make antibodies to combat antigens. These cells internalise antigens before presenting them to T-cells.

Osteoclasts
Osteoclasts are terminally differentiated cells of the macrophage lineage that re-absorb bone matrix. In rheumatoid arthritis, they aid joint destruction.

T-cells
Similar to B-cells, T-cells differ in the fact that they have special receptors on their surface. They assist the maturation of B-cells into plasma cells.


© Science Photo Library

Plasma cells
Plasma cells develop when B-cells are activated under stimulation by T-cells. They are a larger and more specialised antibody-producing cell.

Macrophages
The role of the macrophage is to engulf and digest cellular debris and pathogens, stimulate B-cells and release enzymes and proteins.

Synovial membrane
The synovial membrane is the soft tissue that lines the non-cartilaginous surfaces within joints. With rheumatoid arthritis, the synovium becomes irritated and enlarged.

Why is there no cure for the common cold?

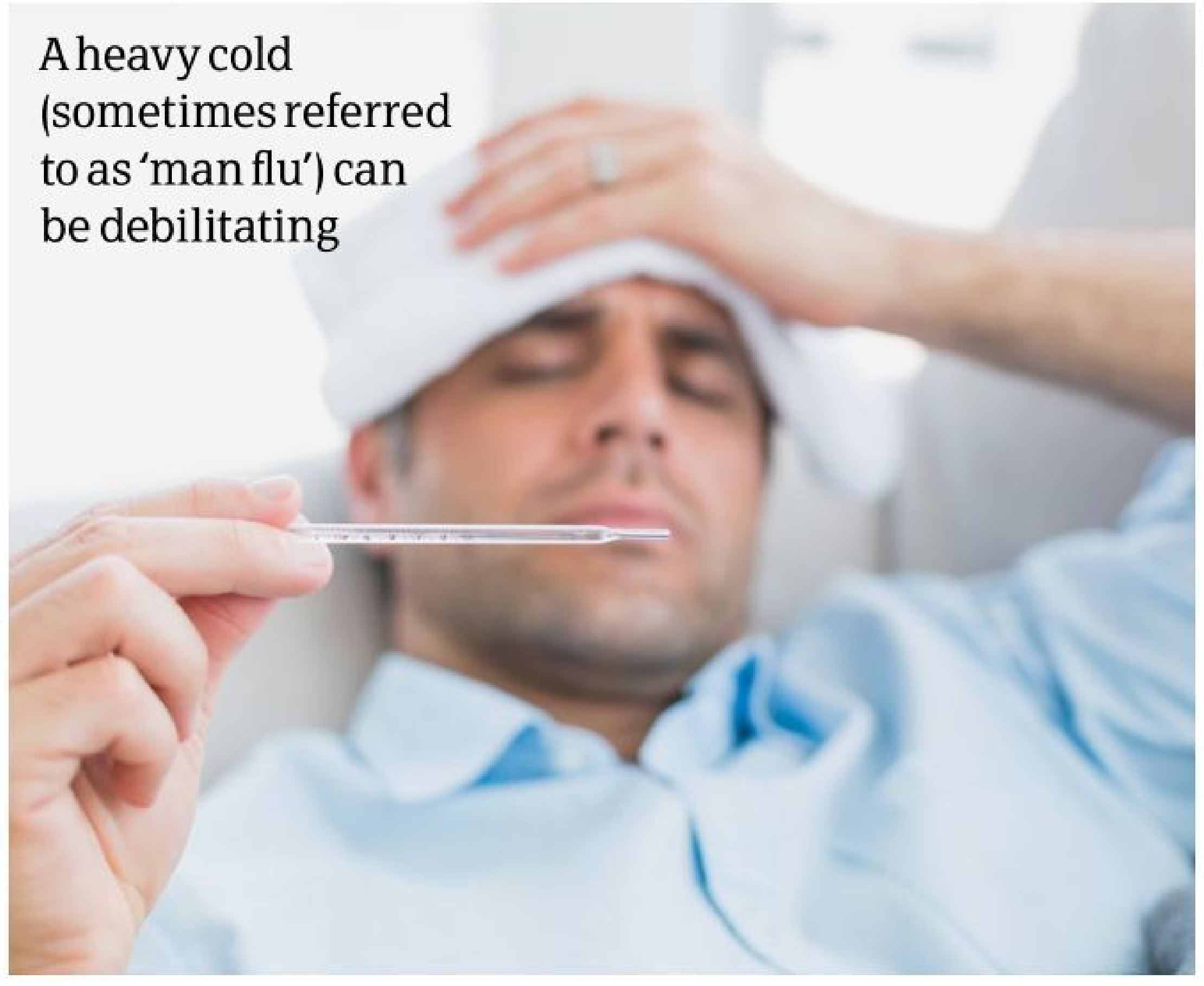
A general term for over 200 different viruses, why is the common cold so 'incurable'?

The common cold is a viral infection that attacks the upper respiratory tract, including the nasal cavity, the pharynx (back of the mouth) and the larynx (voice box). Every child can get up to 12 colds a year, and in adulthood we continue to get them on a regular basis.

The symptoms of a cold are sneezing, a runny nose, a sore throat and nasal congestion. Young children can also run a high temperature. In the first three days, the cold is highly contagious and is spread to anyone who inhales or touches anything contaminated by the virus. A cold lasts about a week, although a cough can persist for several days afterwards.

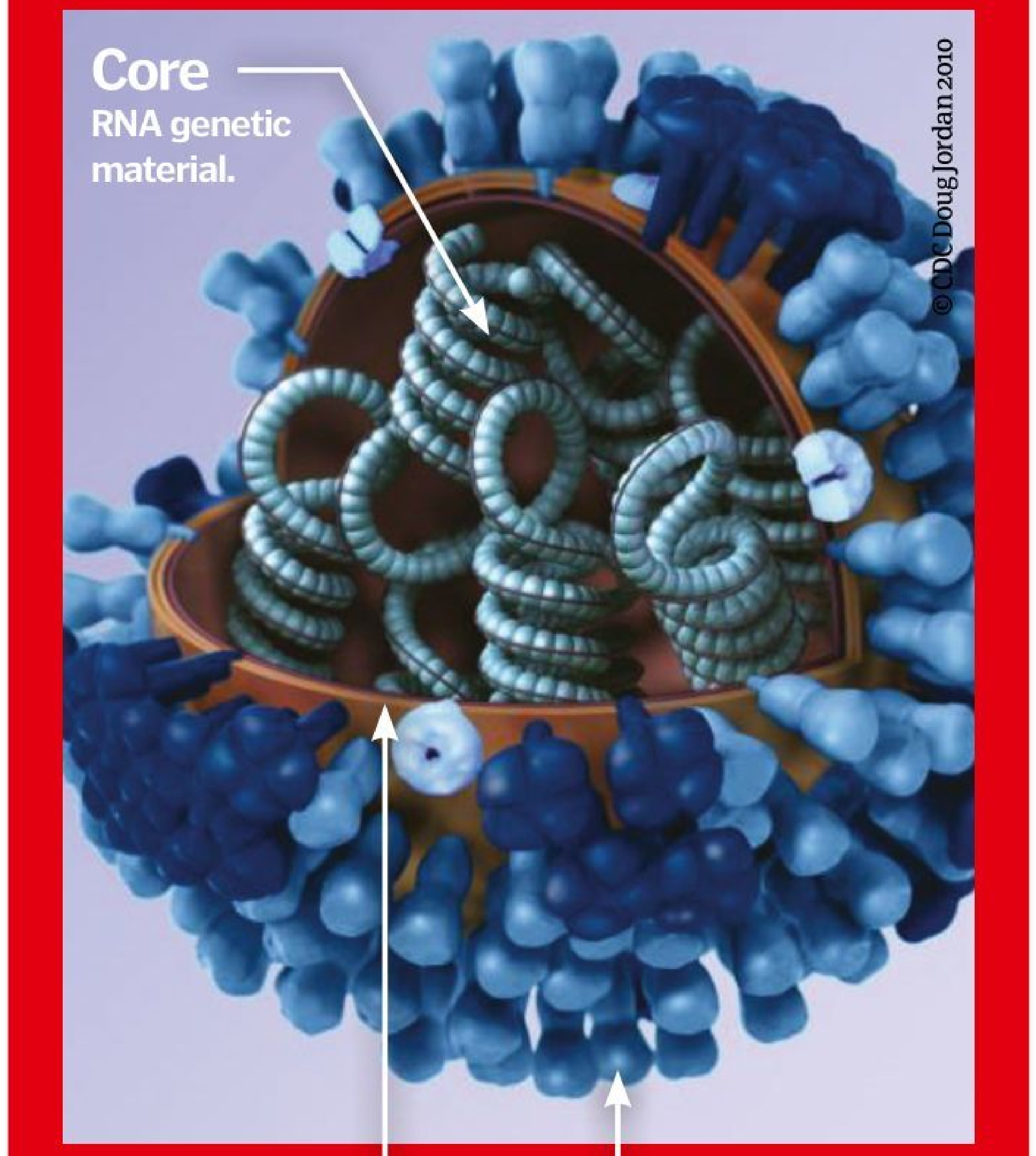
Rhinoviruses, coronaviruses, coxsackieviruses and adenoviruses are just some of the many different types of cold viruses. These viruses stick to the cells of the adenoids at the back of your throat. They quickly reproduce and rupture from the cells to spread to cells in the rest of the upper respiratory tract.

While we can treat the symptoms of a cold, we cannot find a single cure as there are so many types of virus and they mutate rapidly. Therefore, in the time it takes to develop a vaccine, it is no longer useful.


A heavy cold (sometimes referred to as 'man flu') can be debilitating

What is a virus?

Unlike bacteria, which have a cellular structure, viruses are much smaller and must replicate within other cells – for example, within the cells that line the inside of the nose.


© Dr Doug Jordan 2010

Core
RNA genetic material.

Capsid
This protein coat encloses the virus's genetic information within the host cell.

Receptors
These protruding proteins enable the virus to attach to the surface of the host cell.

How a marathon affects your body

Long-distance running puts tremendous strain on the body. Read on for tips on how to train and run safely

© Martineric

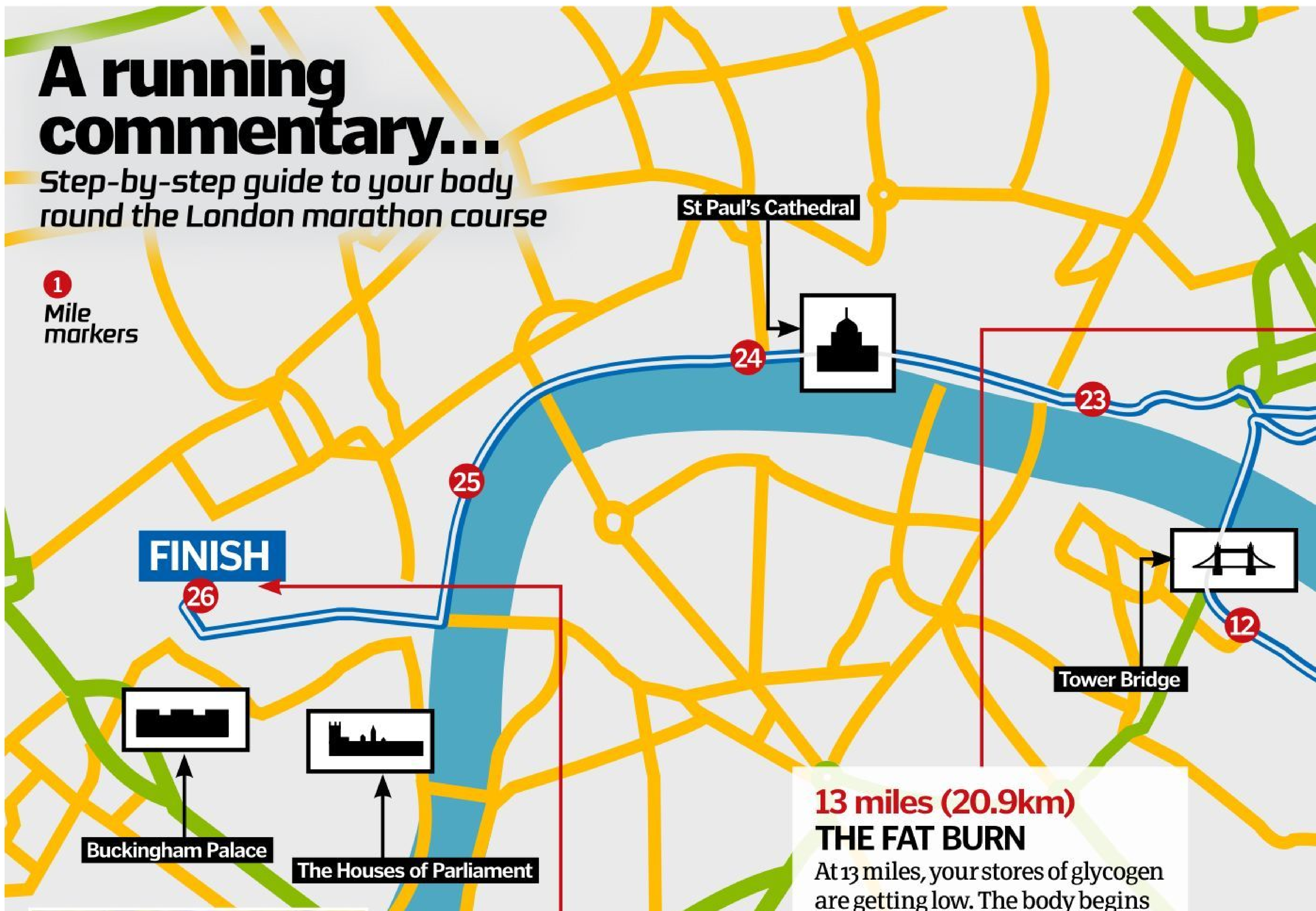
Runners in the NYC Marathon cross the Verrazano-Narrows bridge

© Julian Mason

Athletes led the way in the London Marathon 2009

A running commentary…

Step-by-step guide to your body round the London marathon course



13 miles (20.9km)
THE FAT BURN

At 13 miles, your stores of glycogen are getting low. The body begins to burn fat at this stage and your thirst continues.

© Alex lomas

26.2 miles (42.2km)
HOMEWARD BOUND

Your joints may be sore, you may well feel mentally and physically exhausted, but the finish is in sight. One final push before glory is all yours.

Preparing for your first marathon

It is possible to get race-ready in just 16 weeks, even if you've never run a marathon before. For the marathon newcomer, your fitness must be at a reasonable level before you even start training, and ideally you should have about six months' worth of running experience under your belt, in which you run around 15 miles a week. You should be able to run five miles comfortably in one go.

A good training plan should consist of three to four runs a week, gradually increasing your weekly mileage from 15 miles up to 35 miles a week. You do this by including three short runs in the week, followed up with a longer run at the weekend. By incorporating hill runs and sprints into your training, you will be able to increase your stamina as well as improve your recovery time.

DID YOU KNOW? *The London Marathon course is the only one in the world that is run in two hemispheres – east and west*

Post-marathon advice

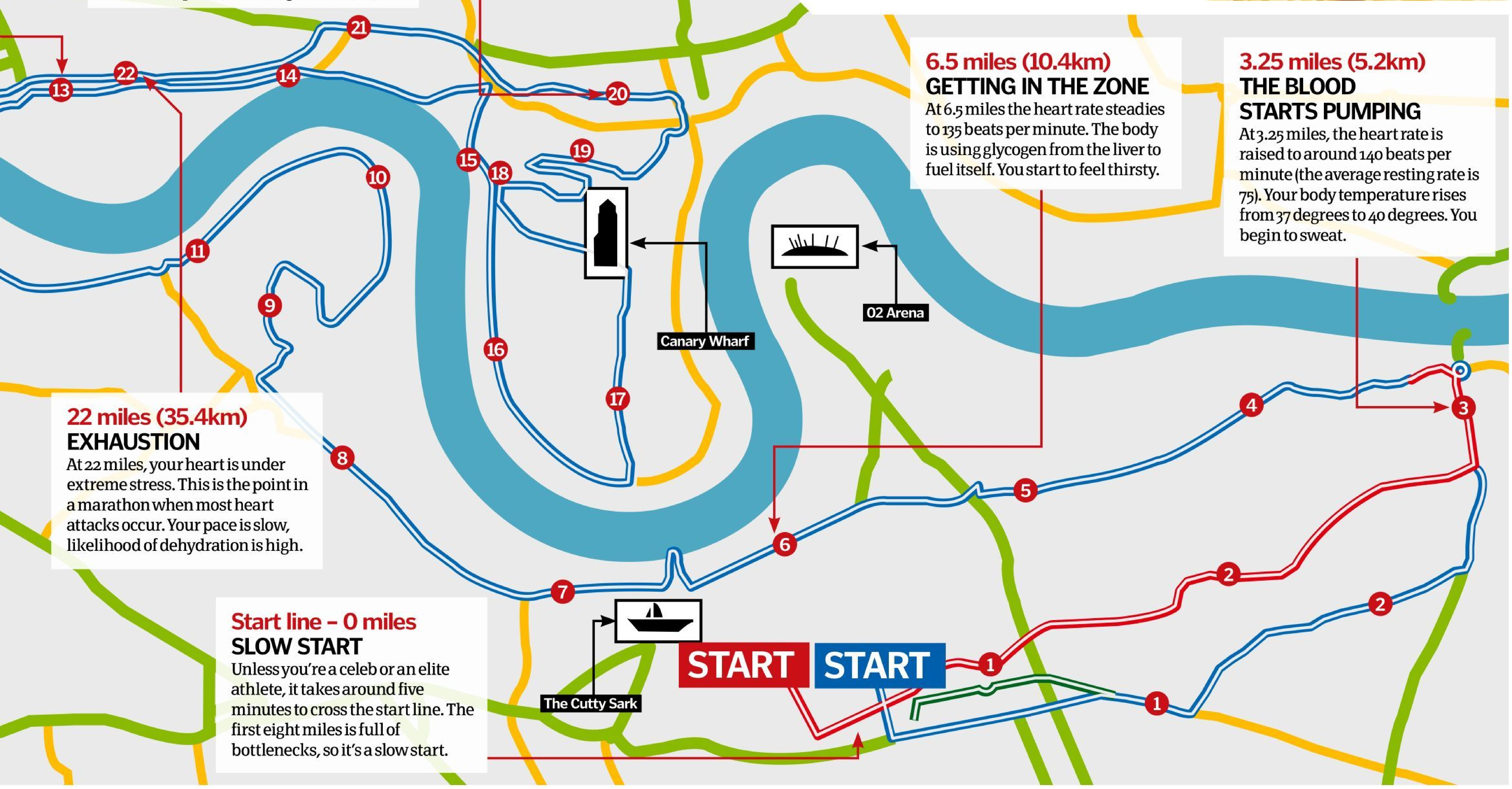
The body is going to feel pretty used and abused post-marathon. Fight the urge to sit or lie down immediately afterwards – keep walking to avoid cramping. Refuel and rehydrate yourself, and change into dry clothes before the cold sets in. In the evening it's wise to replace those carbs you've used during the race, then take an easy walk the next day. Avoid any temptation to run. It's recommended to take one day off per mile you've run, to aid your recovery.

Hitting 'the wall'

'The wall' is a metaphorical term to describe the marathon runner's worst nightmare. It hits at around the 20-mile marker, making the hardcore runner feel temporarily 'pooped', while plaguing the inexperienced runner with agonising body cramps and dehydration.

This stage happens when the body's glycogen supplies run out and the body instead switches to fat reserves for fuel. Glycogen comes from carbohydrates in our food and is stored in the liver and muscles. We can store around 7,500KJ of glycogen in our bodies, and you'll use up 400KJ of this per mile.

To help prevent hitting 'the wall' runners should carbo-load before a race, which means eating pasta the day before. It's often recommended to fuel up during the race by consuming carb gels or beans while you run.



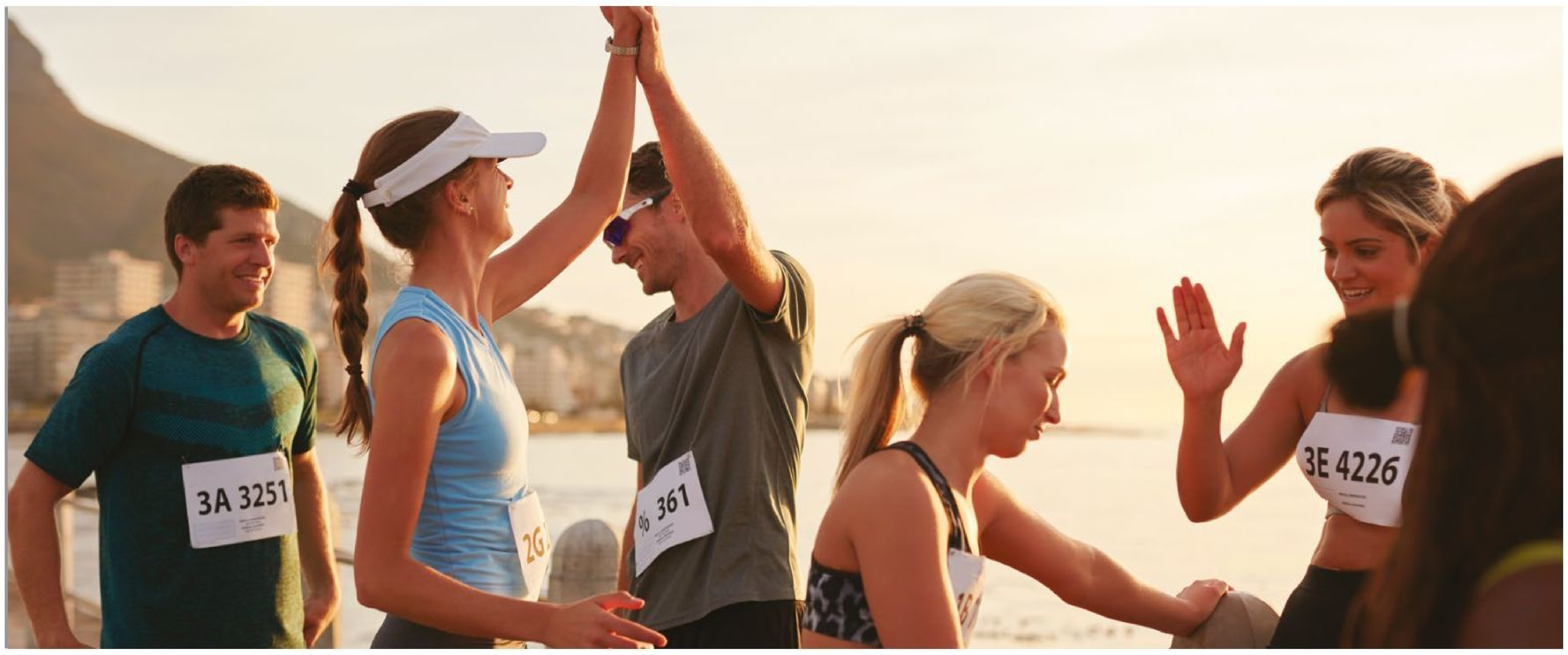
20 miles (32.1km)
THE WALL
At 20 miles your glycogen supplies have run out and your muscles now break down your fat to fuel themselves. Blood sugar is low making you feel faint. Joints become sore from the impact of running on the road.

6.5 miles (10.4km)
GETTING IN THE ZONE
At 6.5 miles the heart rate steadies to 135 beats per minute. The body is using glycogen from the liver to fuel itself. You start to feel thirsty.

3.25 miles (5.2km)
THE BLOOD STARTS PUMPING
At 3.25 miles, the heart rate is raised to around 140 beats per minute (the average resting rate is 75). Your body temperature rises from 37 degrees to 40 degrees. You begin to sweat.

22 miles (35.4km)
EXHAUSTION
At 22 miles, your heart is under extreme stress. This is the point in a marathon when most heart attacks occur. Your pace is slow, likelihood of dehydration is high.

Start line – 0 miles
SLOW START
Unless you're a celeb or an elite athlete, it takes around five minutes to cross the start line. The first eight miles is full of bottlenecks, so it's a slow start.



THE FUTURE OF MEDICINE

How are we going to beat the world's deadliest diseases?

Medical science has produced some incredible solutions to challenging problems over the decades, from antibiotics to fight bacterial infection, to imaging technologies to look inside patients without using a knife. It's hard to predict what will happen next, but science has recently opened some really exciting doors to the future of medical treatment.

Medicine is no longer just about biology and drugs. Computing, engineering, nanotechnology, quantum physics, and many more disciplines are leaking over into medical tech and providing brand new solutions to age-old problems.

In the hospitals of the future, augmented reality could allow surgeons to see through their patients, and contact lenses could monitor blood sugar for diabetics. Prosthetic limbs linked directly to the nervous system could allow amputees to move and feel just by thinking, and 3D printers could be utilised to create custom medical kit, or even fully working replacement organs, on demand.

We are learning how to retrain our own immune systems to fend off deadly diseases, and we are developing technology that could allow our own genetics to be tweaked and changed on the go. The scientific community has access to a massive and rapidly expanding pool of data from patients the world over, and as we dig deeper into the biochemistry of illness, new ways to precisely treat disease are set to appear.

One day, wearable tech and at-home test kits could monitor for the first signs of sickness, and custom treatments might be delivered based on our own unique genetic and biochemical fingerprints, minimising side effects and maximising our chances of recovery.

How germs spread

Body fluids

Blood, saliva, semen and breast milk can all carry disease

Liquids provide an excellent way for pathogens to travel from one place to another. Precautions are always taken when dealing with body fluids in hospitals and labs, because contaminated body fluids can transmit diseases like mumps, hepatitis and HIV.

Skin to skin contact

Some infections are quickly spread by direct contact

Chickenpox, cold sores, head lice and warts can all be transmitted by touching someone with the infection; the viruses, bacteria, or parasites simply move from one person to another. Some of these examples can also survive on inanimate surfaces for a short time.

Food and drink

Contaminated food and drink carry pathogens into the gut

The acidity of the stomach provides some protection against infection, but it can't stop everything. Pathogens enter through the mouth, and either set up home in the digestive tract, or move into the body through its walls.

WARNING DO NOT FILL ABOVE THE LINE
DANGER
DESTROY BY INCINERATION
6

Droplets

Pathogens can be transmitted short distances by drops of liquid in the air

Tiny drops of fluid released by a cough or a sneeze travel around a metre before they settle onto door handles, surfaces and skin. It's an easy way for respiratory infections to spread. Examples include colds, flu and rubella.

Preventing history's biggest killers

Vaccinations teach the immune system how to fight, before it encounters the disease

Our natural defence against disease is our immune system. It's an army of cells that work together to patrol the body and destroy anything that shouldn't be there. It's split into two parts, a fast-response 'innate' system, that wages war at the first sign of trouble, and a slow, specialised 'adaptive' system that delivers a stronger and more focused attack.

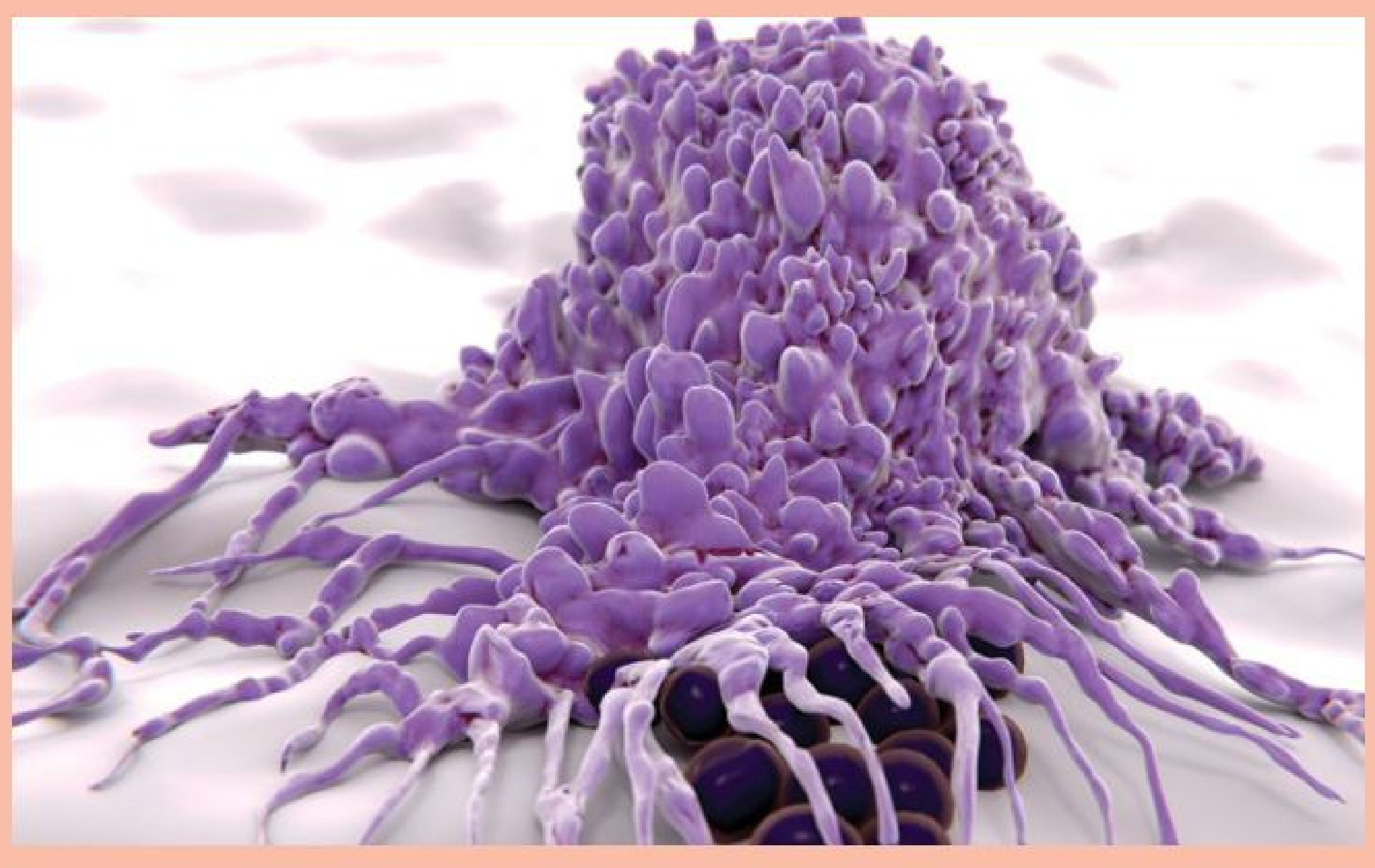
The first time the immune system meets a new infection, it takes up to a week for the specialised immune cells to appear. In this time, the pathogen can multiply, and people can become very sick. Vaccinations bypass this step by giving the immune system a chance to train beforehand.

The first vaccine was developed by Edward Jenner in 1796. He noticed that milkmaids didn't catch smallpox; they were exposed to a similar disease, cowpox, and their immune systems were better trained. Jenner tried infecting children with cowpox, and found that they too gained protection.

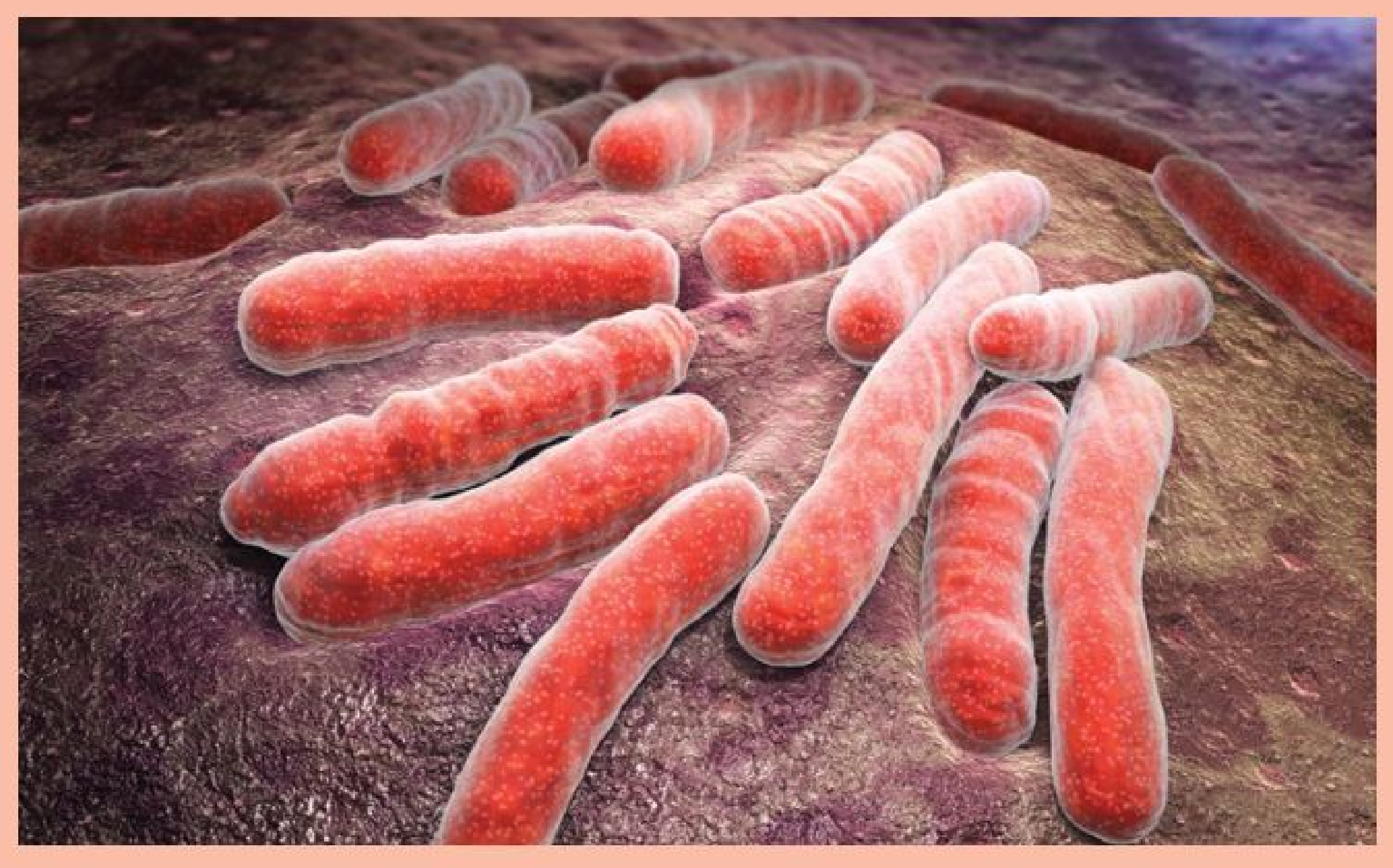
Vaccinations have been developed against dozens of infectious diseases, and they are now being made to teach the immune system to fight other illnesses too.

Training the immune system

Vaccinations are like a training program for your immune system, giving it a sneak peek at enemies that it might encounter in the future so that it can prepare in advance. They can be made in different ways, but usually contain inactive bacteria or viruses, or examples of molecules that the pathogens make.



When the vaccination has been injected, your immune system comes to have a look. It will examine the parts of the pathogen and work out the best way to attack, as though it were fighting the real thing. After the vaccine has been cleared up, some of the cells that fought it remain in the body on patrol as 'memory cells'.

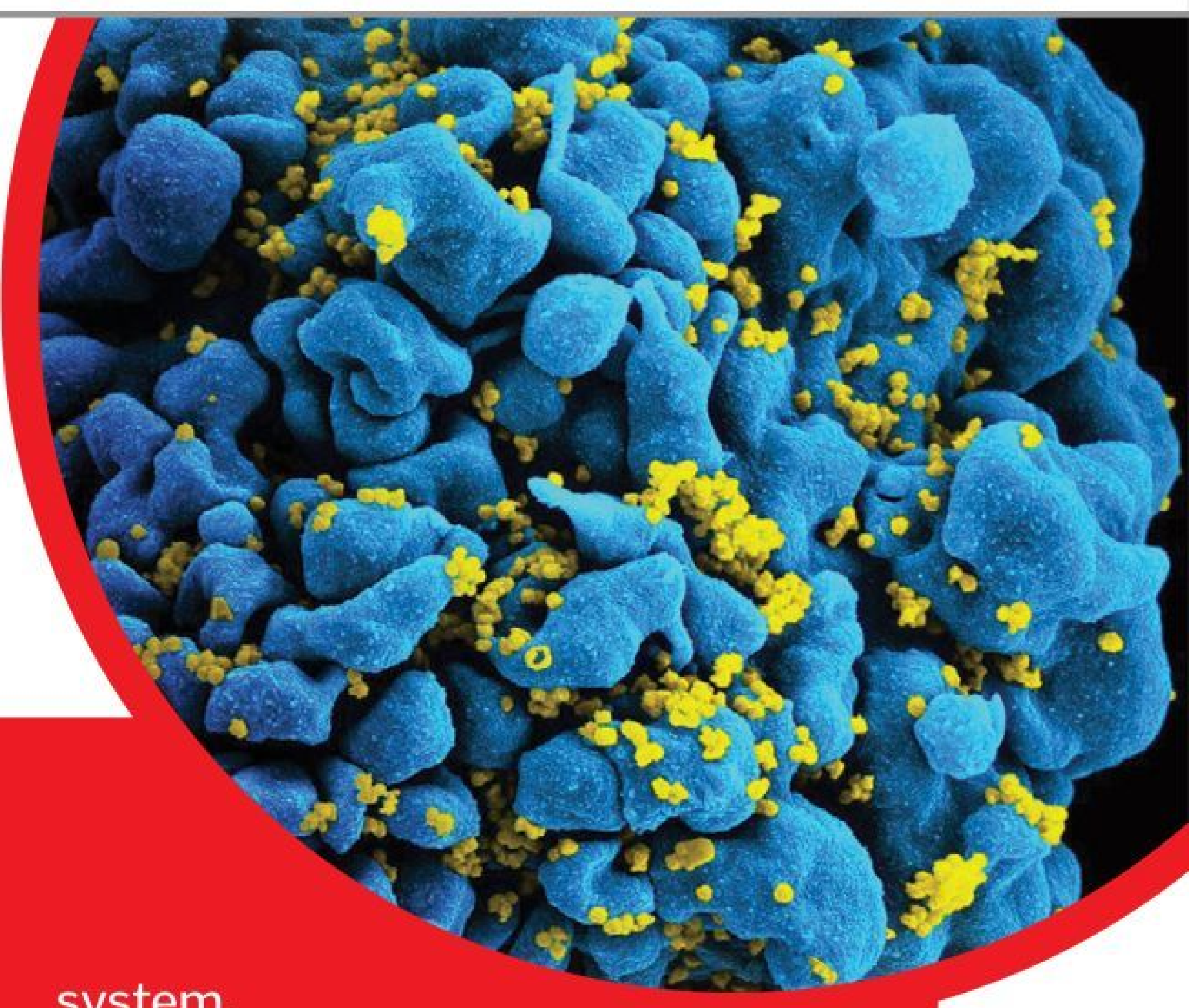


When you encounter the real pathogen, your immune system will be ready to respond. Instead of spending time working out what to do, the memory cells left over from the vaccine instantly clone themselves, producing an army of cells that can clear the infection before you get sick.

© Thinkstock

The end of HIV

How do you hunt down a virus that's hiding in your own immune system?



Human immunodeficiency virus, more commonly known as HIV, hijacks the immune system. The virus gets inside, inserts its genetic code into the genome of a cell, and transforms it into a factory to make more of the virus. While this is happening, the cell is unable to function normally, and gradually as more and more cells are taken over, the immune system is left seriously weakened. The result is known as acquired immune deficiency syndrome (AIDS).

HIV is now treatable with a combination therapy that stops the virus from replicating. The amount of virus often dips so low in the blood that the disease can't be passed on. Transmission from mother to child is also being eliminated with new drugs. However, not everyone has access to treatment.

The gold standard for the future of HIV medicine would be a vaccine that can teach the immune system to neutralise the virus with a coating of antibodies. In theory, this could be used not only to prevent infection, but also to stop the disease coming back in people who have some virus still hiding in their systems.

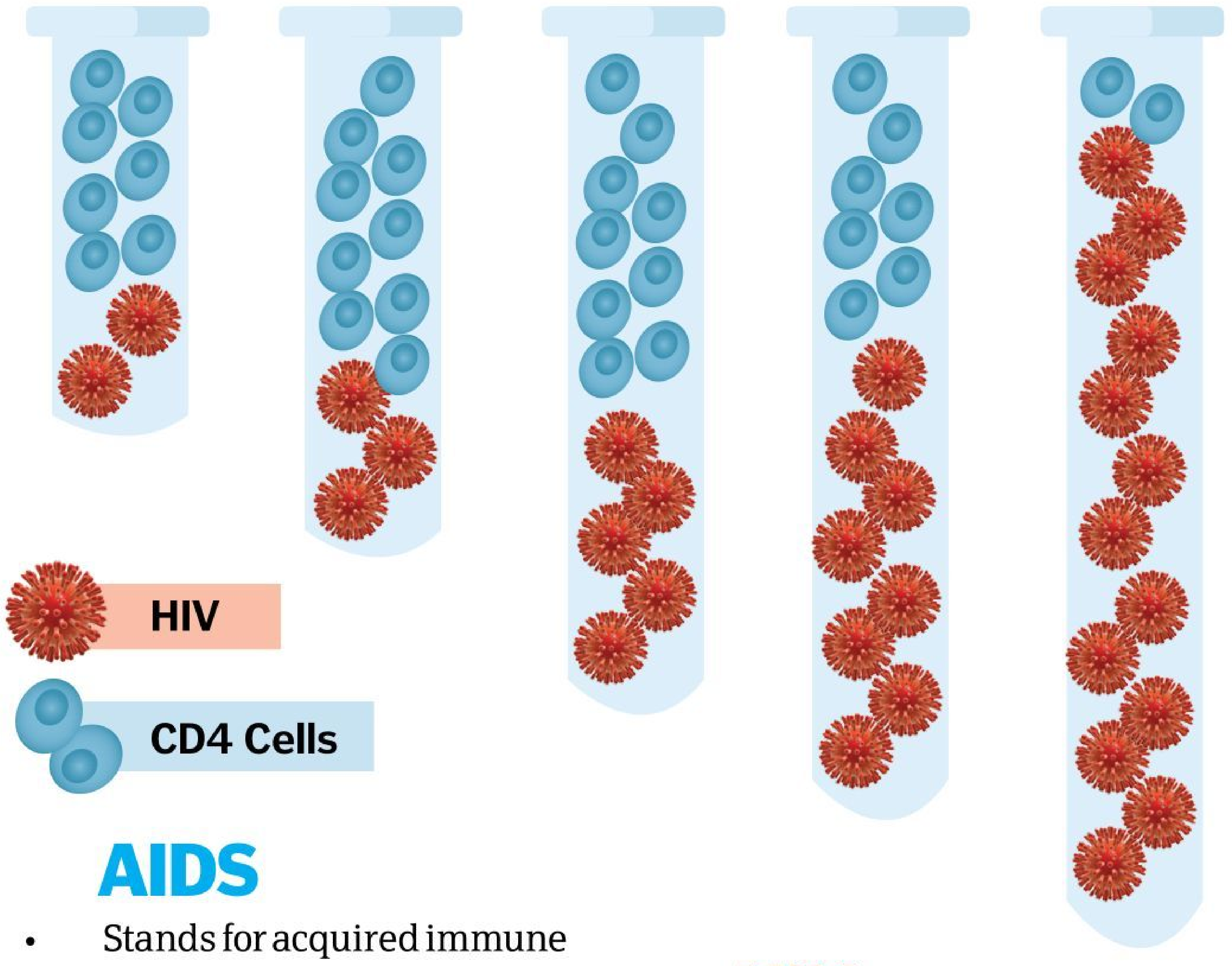
This is a huge challenge; the virus shape-shifts to avoid detection, and the immune system doesn't usually respond. But new vaccines are being trialled all the time, and as our understanding of HIV and the immune system improves, we are inching closer to making it a reality.

How hard is it to cure?

HIV stitches its genome into the genome of immune cells, so that the two are permanently linked together. Antiretroviral treatment can stop the virus from making copies of itself, but they can't get rid of it completely unless the immune cells themselves are killed.

This has been done once, in 2007. The Berlin Patient had cancer and needed a bone marrow transplant. His own immune system, carrying the HIV virus, was destroyed, and replaced with donor cells. They had a genetic mutation that made it harder for HIV to infect them, and the patient was cured.

Bone marrow transplants are risky, however, and there aren't enough donors available, so it's not a practical solution to rid the world of HIV altogether.



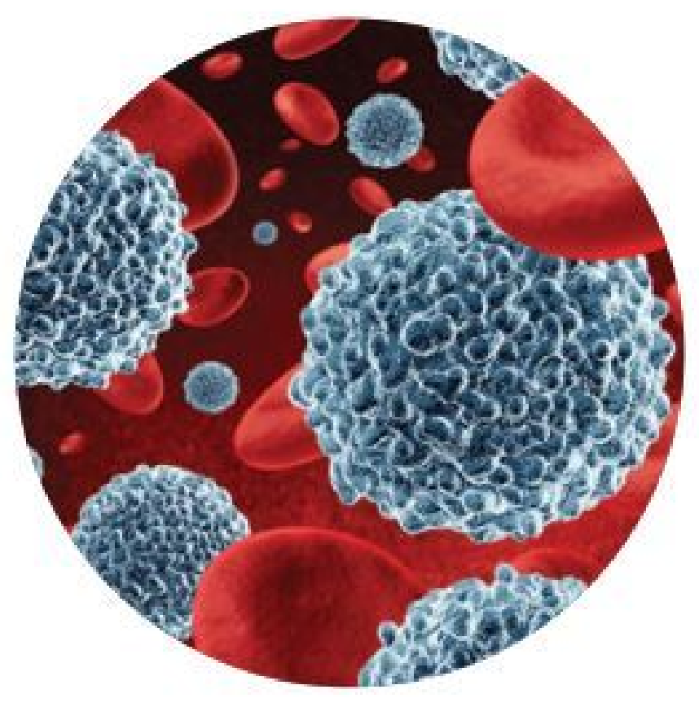
AIDS

- Stands for acquired immune deficiency syndrome
- Is the disease caused by HIV
- Takes advantage of the damaged immune system that is unable to fight it
- People die due to infection or resulting cancer

HIV

- Stands for human immunodeficiency virus
- Is the virus that causes AIDS
- It infects the immune system
- Infection compromises the cells of the immune system

Timeline



1981
Men in California start to fall ill with unusual infections after their immune systems become weakened.

1983
Scientists discover that human immunodeficiency virus (HIV) is the cause of acquired immune deficiency syndrome (AIDS).

1985
Commercial blood tests for HIV are invented, allowing screening to begin.

1987
The first drug treatment for HIV, azidothymidine, is approved.

1996
Triple-drug therapy is introduced, turning HIV infection into a long-term disease.

2007
A single patient in Berlin is cured by a pioneering bone marrow transplant.

Future
A vaccine is developed to train the immune system to attack HIV.

Future
A drug is developed to reveal HIV lurking in dormant cells.

37 million

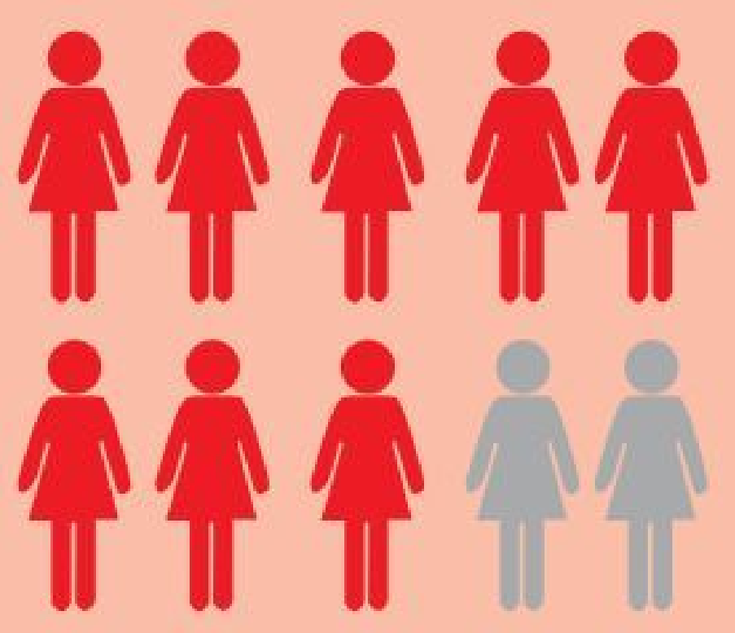
In 2015, nearly 37 million people were living with HIV

Over half of people with HIV can't access treatment

1.1 million

people die as a result of AIDS each year

HIV is transmitted through body fluids, including blood, semen and breast milk



8 out of **10** pregnant women with HIV receive treatment to minimise the risk to their child

HIV infects the immune system, crippling the body's defences

40%

of people with HIV don't know they're infected

Antiretroviral therapy stops the virus replicating

Condoms, HIV testing, and circumcision help to reduce transmission

HIV puts people at risk of catching other diseases like tuberculosis

Can cancer be cured?

Huge progress has been made over the past century, but what happens next?

Cancer is an ancient disease; tumours have been found in Egyptian mummies, and even in the fossils of dinosaurs. It happens when genes involved in growth and repair go wrong. Affected cells make copy upon copy of themselves, and these new cells start to break away, travelling around the body and making yet more copies elsewhere.

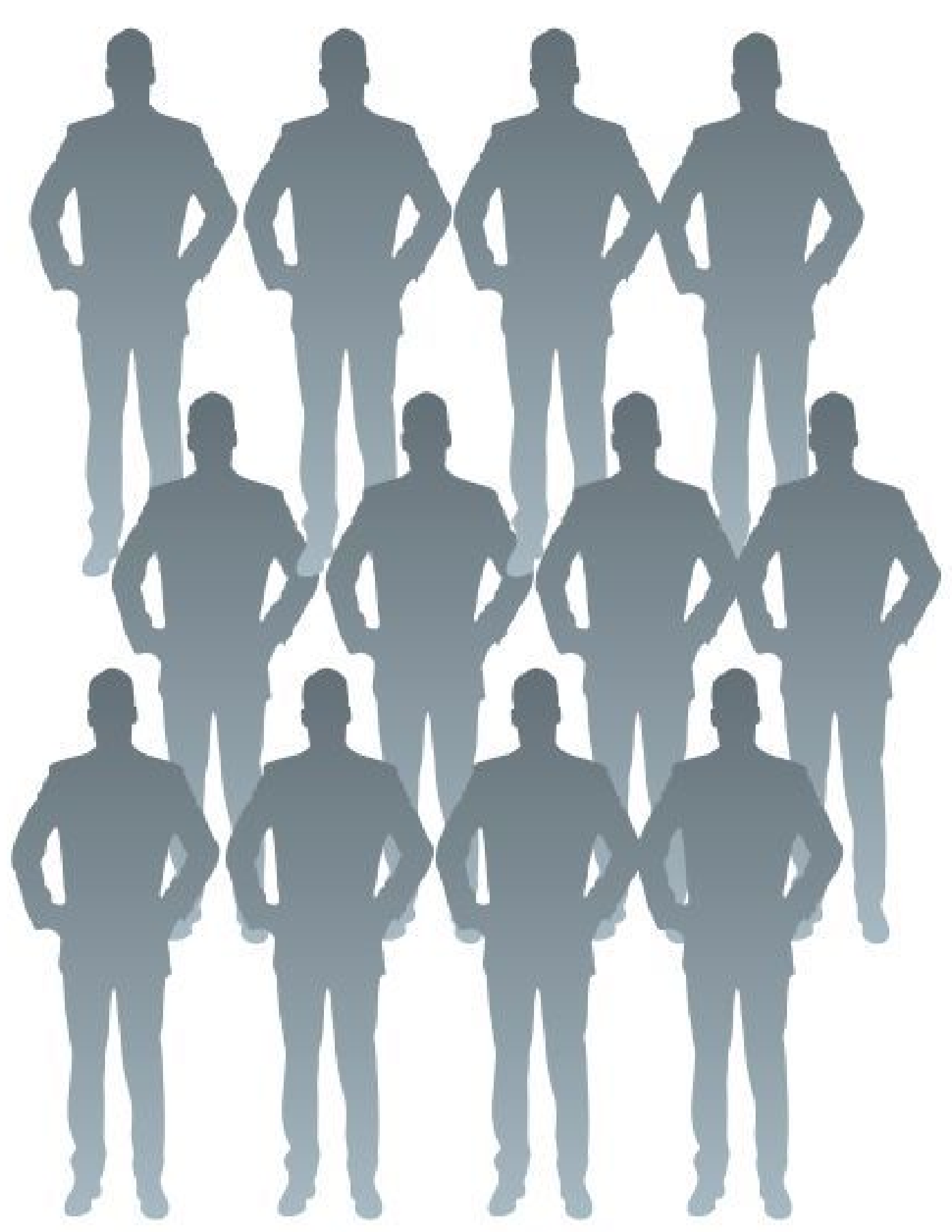
If cancer is caught early, it can already be cured. If the tumour is removed, the cancer is gone. However, once the cancer has spread it is harder to treat, and the more it spreads, the less likely people are to survive.

Stopping cancer before it really starts would be the best option. Vaccinations might be used to train the immune system to recognise cancer cells, or a routine blood or breath test could be developed to pick up the earliest signs of the disease. However, the likelihood of cancer increases with age, and with people living longer the incidence is rising.

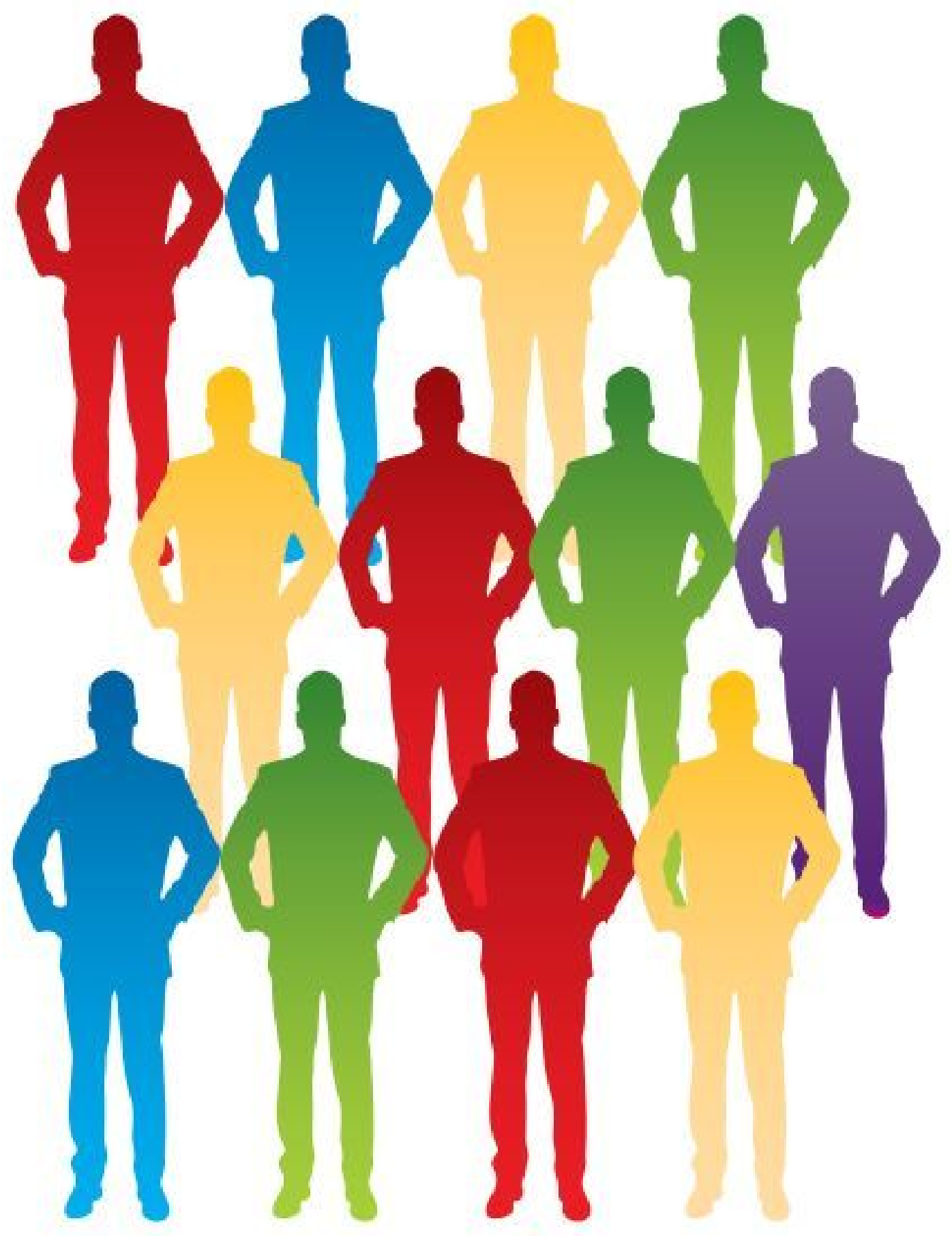
For those who do develop the disease, several futuristic treatment options are already being developed. Future humans could end up having their immune systems retrained and augmented, or they might receive genetically engineered viruses designed specifically to infect and kill the tumour. We might even be able to switch genes on and off inside tumour cells to halt their growth.

The future of cancer medicine

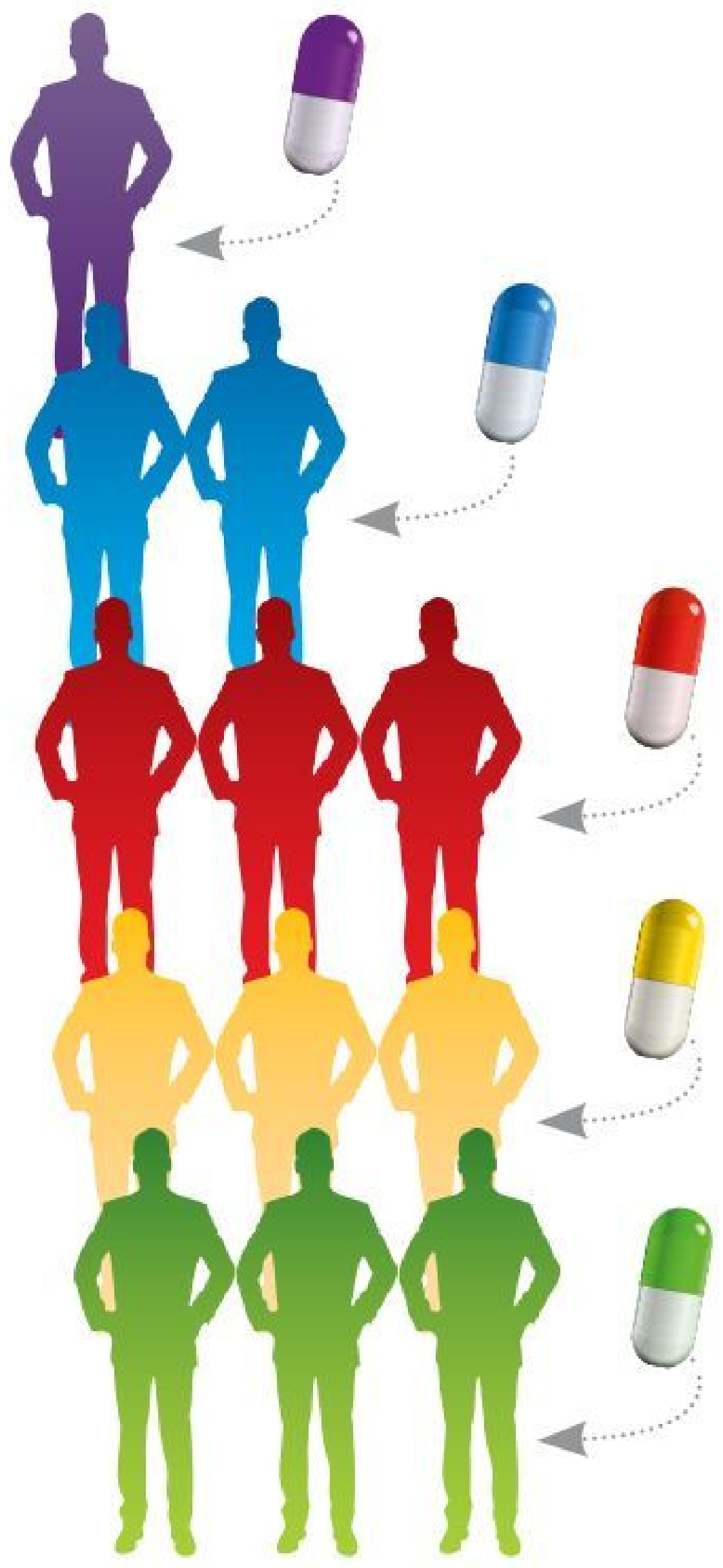
Matching people to the right treatment could be the answer to controlling cancer



Group of patients
Several people might have brain cancer, but not all brain cancers are the same.



Genetic testing
The patients are tested to find out the exact genetic and chemical makeup of their tumour.



Treatment matching
Patients are matched with treatments that specifically target the weaknesses of their own cancer.

Where is the cancer cure?

Cancer gets a lot of research money, and thousands upon thousands of scientists are working to try to find the cure, so where is it? If you can cut the tumour out before it has a chance to spread, you can cure it, but if any cells have escaped they need to be found. Radiotherapy and chemotherapy can help to mop up stragglers, but they don't always work, and some cancer cells develop ways to avoid them. The big challenge is that everyone is different, and so too are everyone's cancers. And tumours don't just differ between people, they also change over time. The challenge is to find out how they change, and how these different weaknesses can be targeted with treatments.

Timeline

1846
The invention of general anaesthetic paves the way for surgery to finally remove tumours.

1880s
The first mastectomy is performed, finally providing treatment for breast cancer.

1903
Radium is used to treat skin cancer, in what is the first example of radiotherapy.

1949
The first chemotherapy drug is approved. It is nitrogen mustard, a WWII weapon.

1950s
Smoking is finally shown to cause lung cancer, encouraging millions to give up.

1990s
Cancer mortality starts to drop in developed countries as diagnoses and treatment improve.

Future
Personalised medicine becomes reality, with patients matched to treatments based on their genes.

Future
A simple blood test is developed to pick up the very earliest signs of cancer.

14 million people are diagnosed with cancer each year

8 million people die of cancer each year

Lung cancer is the most common type of cancer in men

Breast cancer is the most common type of cancer in women

The older you are, the more likely you are to get cancer

Cancer is not contagious, but it can be genetic

Viral infections can cause some cancers

The earlier cancer is detected, the easier it is to treat

Lifestyle changes could prevent a third of cancers

Eliminating malaria

This deadly disease is carried by mosquitoes, but work is being done around the world to wipe it out

Just one mosquito bite is enough to kill you in some parts of the world. Inside the midgut of Anopheles mosquitoes, gametocytes from the plasmodium parasite mature and combine. These are the equivalent of human sperm and eggs, and the result is hundreds of newly formed parasites ready to infect their next victim.

The parasites migrate up to the mosquito's salivary glands, and when it feeds again they enter the human bloodstream. They infect cells in the liver and begin to divide, before spreading back into the blood. As they continue to grow, the cells split open, releasing even more parasites and causing havoc for the body.

Malaria parasites can't reproduce without both mosquitoes and humans, giving us a tantalising opportunity to eliminate them. One idea is to genetically modify colonies of mosquitoes and release them to breed with their wild counterparts; this could be used to introduce damaging genetic traits into the population, either killing the parasites, or killing the mosquitoes themselves. Another option is to develop fungi that can infect and kill the insects.

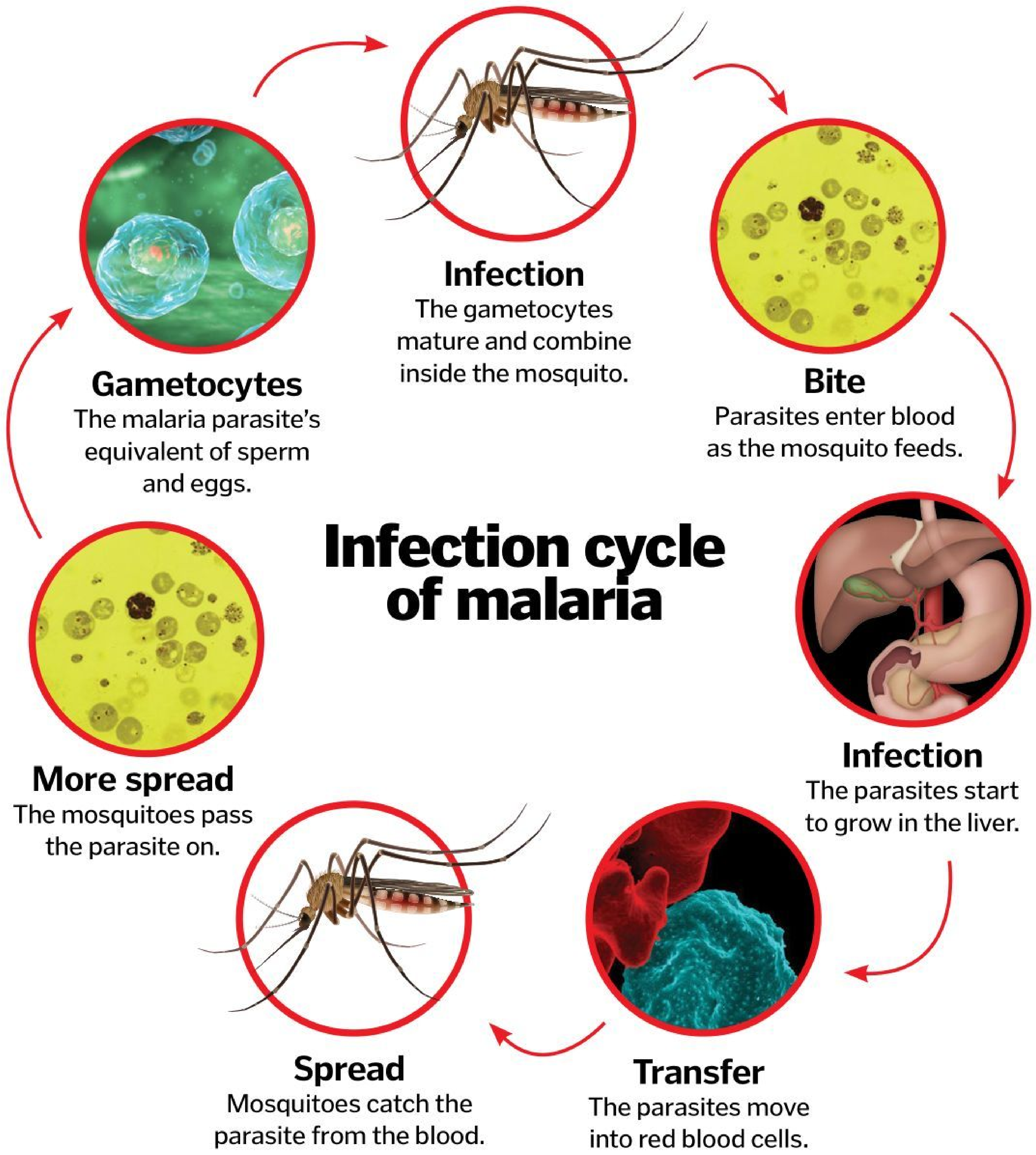
Other options for elimination include designing new insecticides to keep insect numbers down, and developing a vaccine to halt transmission.

Global elimination is tough

The World Health Organisation first initiated an attempt to rid the world of malaria in 1955. The idea was to use a combined attack, spraying houses to get rid of the mosquitoes, and using antimalarials to kill the parasites. They had some successes in areas where the climate was moderate and mosquitoes thrive only during certain seasons, but in other places the program didn't work as well.

Mosquitoes started to become resistant to pesticides, and the parasites resistant to treatments. This, combined with wars, political unrest, and patchy access to resources, meant that coordinating a global attack against malaria became impossible.

In 2015, the WHO reissued their challenge. But today we are facing even stronger versions of the parasite and vector, and new weapons are needed to eliminate them.



Infection cycle of malaria

Infection
The gametocytes mature and combine inside the mosquito.

Bite
Parasites enter blood as the mosquito feeds.

Infection
The parasites start to grow in the liver.

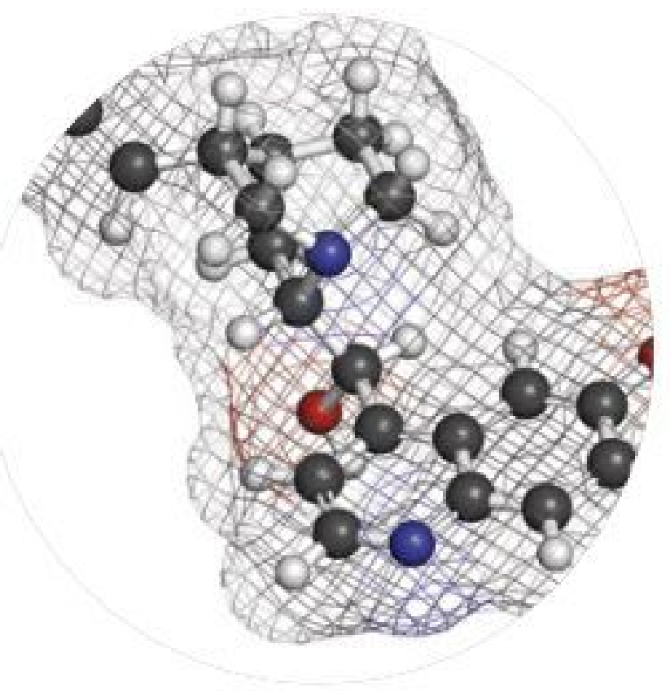
Transfer
The parasites move into red blood cells.

Spread
Mosquitoes catch the parasite from the blood.

More spread
The mosquitoes pass the parasite on.

Gametocytes
The malaria parasite's equivalent of sperm and eggs.

Timeline



1600s
Peruvian tree bark is used to treat malaria, eventually leading to the modern drug quinine.

1880
The parasite that causes malaria is discovered in blood samples taken from patients.

1897
It's discovered that mosquitoes are able to transmit malaria from one person to another.

1939
The DDT pesticide is invented, allowing people to control numbers of malaria-carrying mosquitoes.

1951
Malaria is wiped out in the US after a government eradication program sprays millions of homes.

2015
The World Health Organisation endorses a new strategy to eliminate malaria for good.

Future
Malaria-carrying mosquitoes are wiped out by genetically modified insect mates.

Future
The world is declared malaria free thanks to the eradication campaign.

10-18
days it takes for malaria parasites to reproduce inside a mosquito

Malaria was first written about in Ancient China in 2700 BCE

3.2
billion people live in regions where they could catch malaria

400,000
people die of malaria each year

70%
of malaria deaths are children under the age of 5

Malaria is caused by parasites that infect humans and mosquitoes

Spraying houses with insecticide is the best way to stop transmission

Last year **95** countries reported cases of malaria

214 Million
cases of malaria in 2015

© Thinkstock

DID YOU KNOW? *The earliest example of human cancer is a 1.7 million year old fossil with a bone tumour*

Halting heart attacks and strokes

Diseases of the heart and blood vessels are the world's biggest killers

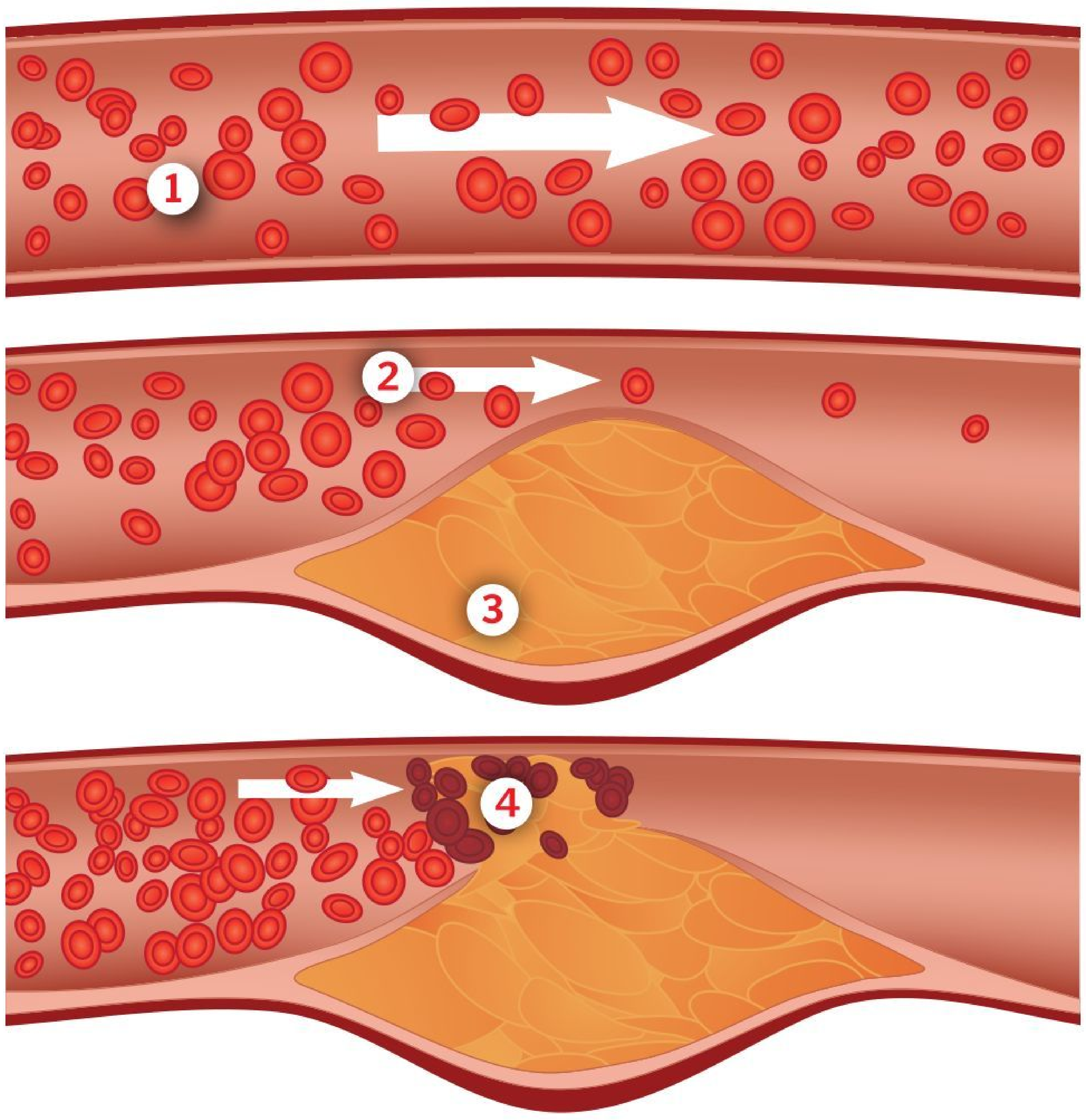
When the body's arteries and veins become clogged with fat, rough plaques form and narrow the tubes. As the blood tries to force its way through the narrow space it swirls and twists, and more damage is done. The fatal blow comes when parts of the blockage break away. Clotting molecules in the blood interpret the roughness as a cut that needs to be sealed. They start to build a clot, and as the circulating blob gets larger, it eventually becomes lodged in the tubes, cutting off the blood supply.

The damage can't always be repaired, but the latest research could change that for the future. Stem cells are cells that haven't yet decided which part of the body to become. With some coaxing in the lab, they can be converted into new blood cells, new skin cells, or even new heart muscle. Harvard scientists have already made a life-size beating heart by convincing stem cells to become heart muscle and growing them on a scaffold. In the future, custom organ replacements could be made artificially on demand.

If this doesn't work, another option is gene therapy, which is already being trialled for heart failure. Genes are delivered to the cells, telling them to make different molecules, and potentially allowing the body to be reprogrammed from the inside out.

How heart disease starts

The slow accumulation of fat can lead to a deadly blood clot



1 Normal vessel
Healthy blood vessels have smooth internal walls, allowing the blood to slip easily around the body.

2 Disruption
When a blockage appears in the vessel, the blood quickly becomes backed up.

3 Plaque
Fatty deposits in the wall of the blood vessel cause it to bulge, narrowing the tube.

4 Clotting
A clot starts to form on the roughened surface, and the blood vessel becomes clogged.

Why haven't we cured it?

Cardiovascular disease is difficult to treat once a catastrophic event has happened; strokes and heart attacks deprive vital organs of oxygen, and the affected tissue quickly dies. If you have a heart attack outside of a hospital, you have just a one in ten chance of surviving, and quarter of people who suffer a stroke will die within a year.

In order to meanigfully improve treatment of cardiovascular disease, we need to be able to repair or replace damaged tissues, or we need to prevent it happening in the first place. Neither one is easy to do.

Timeline

1899
Pharmaceutical company Bayer begin manufacturing a new drug called aspirin in Germany.

1930
The defibrillator is invented, allowing stopped hearts to be restarted with electricity.

1958
The first implantable pacemaker is installed, allowing the heart to be controlled.

1960
The first heart bypass surgery was performed to divert blood around damaged vessels.

1967
The first human heart transplant is performed, allowing damaged organs to be replaced.

1987
The first cholesterol-lowering statin drug hits the market, helping to prevent heart attacks.

Future
Custom-grown replacement hearts are produced from people's own stem cells.

Future
Gene therapy is used to reverse the damage done by heart attacks.

Cardiovascular disease killed

17.2

million people in 2012

Heart attack symptoms include chest, arm and jaw pain, sweating and vomiting

Someone has a stroke every 2 seconds

There are over 2.5 million heart attack and stroke survivors in the UK

Men are more likely to die of heart disease than women

A third of adults in the UK have high cholesterol

The most important risk factors are smoking, diet, exercise and alcohol intake

Stroke symptoms include sudden weakness on one side of the body, confusion and slurred speech

Heart disease and stroke are the first and second most common causes of death

Why do we get headaches?

If the brain can't feel pain, why do headaches hurt so much?

The brain itself may not have any pain-sensitive nerve receptors, but that doesn't mean the inner head can't experience pain… as anyone who's had a headache will know.

The most common form of headache is the tension headache. When the muscles in your body stay semi-contracted for a period of time – for example, when we are feeling stressed and don't seem to be able to relax – this is known as muscle tension. Such tension in the meninges (the membranes that help protect the brain), or the face, neck and scalp muscles activate the body's pain receptors, sending impulses to the brain's sensory cortex and signalling pain and causing a headache.

More frequent in women than men, the primary tension-type headache manifests itself as a dull ache across both sides of the head. Secondary headaches, meanwhile, can be caused by an underlying health condition such as meningitis, a blow to the head or other sinus-related ailments.

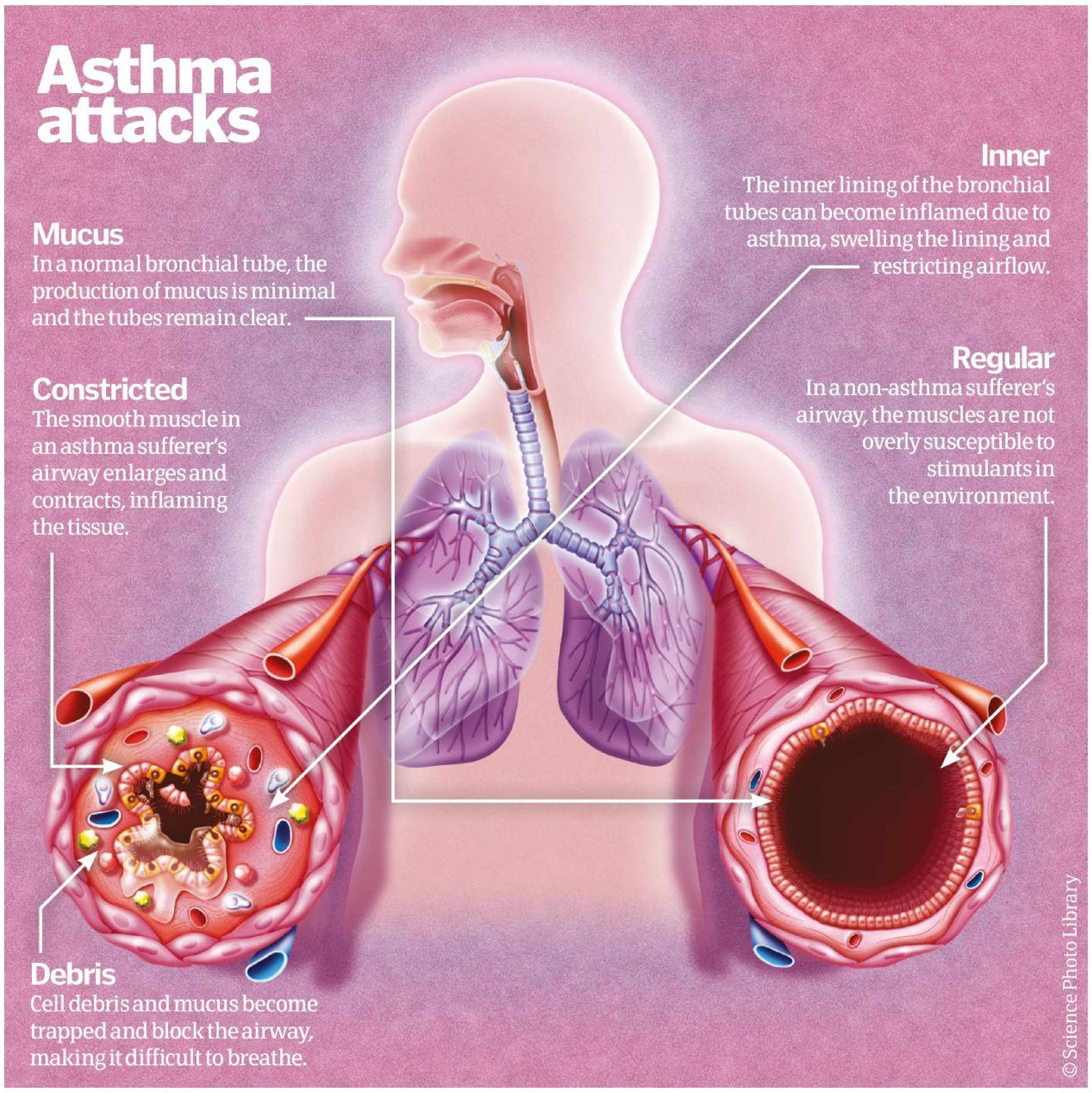
Stress, tension in the head and neck muscles, and the constriction or dilation of blood vessels are just some of the causes of headaches

Asthma

Why does this disease make it difficult for sufferers to breathe?

Asthma is caused by the sudden contraction of smooth muscles in the airways of the body. This is normally due to unusually viscous mucus being produced in abundance in the bronchial mucous glands. One of the primary causes of asthma is the narrowing of bronchial tubes because of inflammation. Asthmatics are overly sensitive (hyperreactive) to stimulants in the environment that can cause the bronchial muscles and tubes to contract. Tubes become irritated and swollen, in turn producing excess mucus and blocking the flow of air. While asthma is often hereditary, it can also be acquired through prolonged exposure to substances such as solder and sulphite.

In severe asthma attacks, the accumulation of additional mucus from the bronchial tree can also inhibit airflow within the airways, making it more difficult for an asthma sufferer to breathe. There are several things that can trigger an asthma attack, including exercising and traffic fumes. To overcome an attack, an asthma inhaler can be used to relax the muscles and widen the bronchial tubes so that normal breathing can be resumed.



Asthma attacks

Mucus
In a normal bronchial tube, the production of mucus is minimal and the tubes remain clear.

Constricted
The smooth muscle in an asthma sufferer's airway enlarges and contracts, inflaming the tissue.

Debris
Cell debris and mucus become trapped and block the airway, making it difficult to breathe.

Inner
The inner lining of the bronchial tubes can become inflamed due to asthma, swelling the lining and restricting airflow.

Regular
In a non-asthma sufferer's airway, the muscles are not overly susceptible to stimulants in the environment.

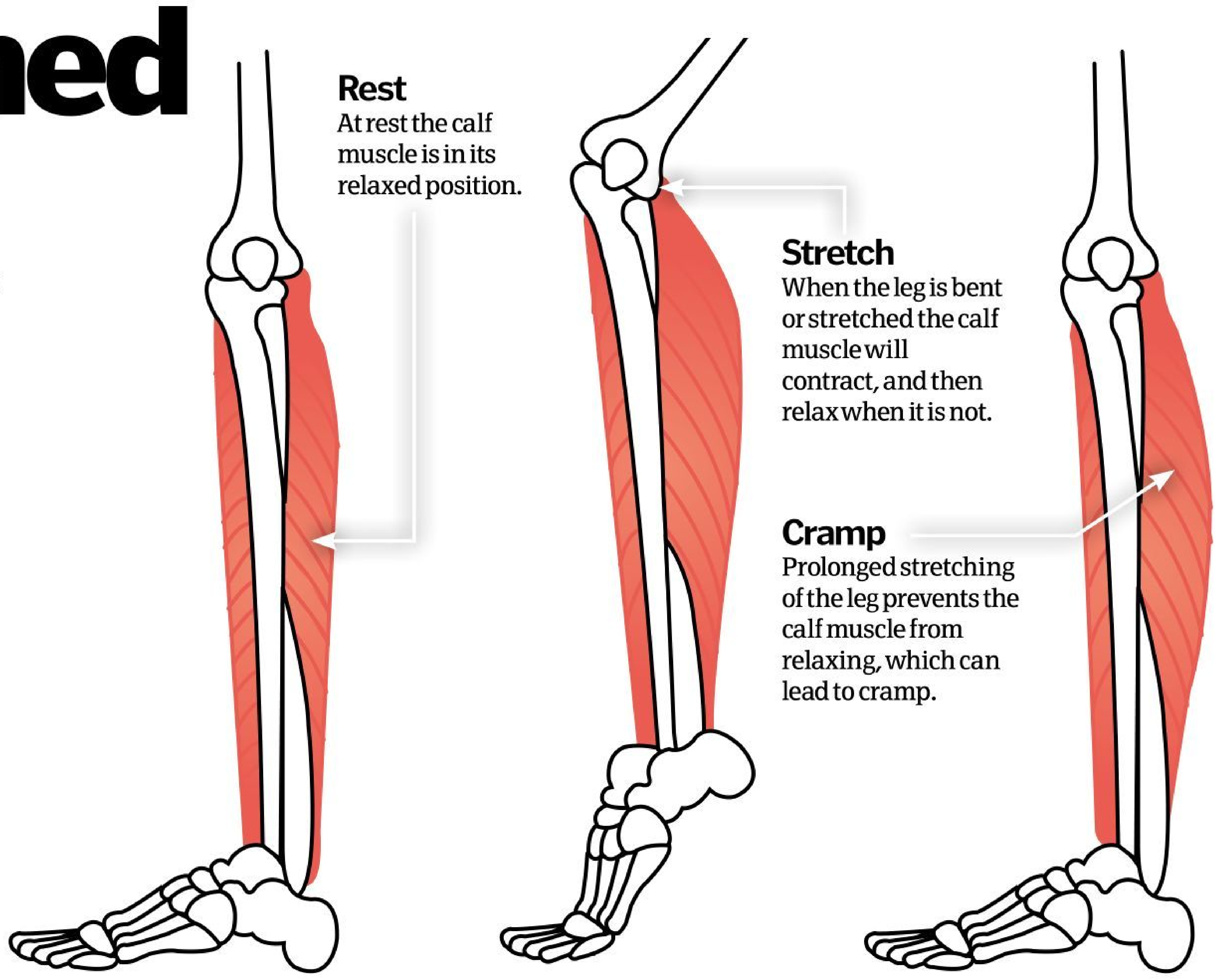
© Science Photo Library

DID YOU KNOW? *Writers' cramp occurs in the hands and lower arms but is actually a form of dystonia, a neurological condition*

Cramp explained

Why do our muscles tense up?

Cramp is an involuntary contraction of a muscle, often in a limb such as the leg, that can cause pain and discomfort for seconds, minutes or, in extreme cases, for several hours. They are most common after or during exercise, coinciding with low blood sugar levels, dehydration and a high loss of salt from sweating. Although the full range of causes is something of a mystery due to limited research in the area, cramp is believed to be the result of muscle fatigue. If a muscle has been shortened through prolonged use but is repeatedly stimulated, it isn't able to properly relax. A reflex arc from the central nervous system to the muscle informs it to continue contracting when it is not necessary, leading to a painful spasm known as cramp as the muscle continually attempts to contract. This is why athletes pushed beyond their limits, such as football players who have to play extra time in a soccer match, and long-distance runners, will often experience this condition.



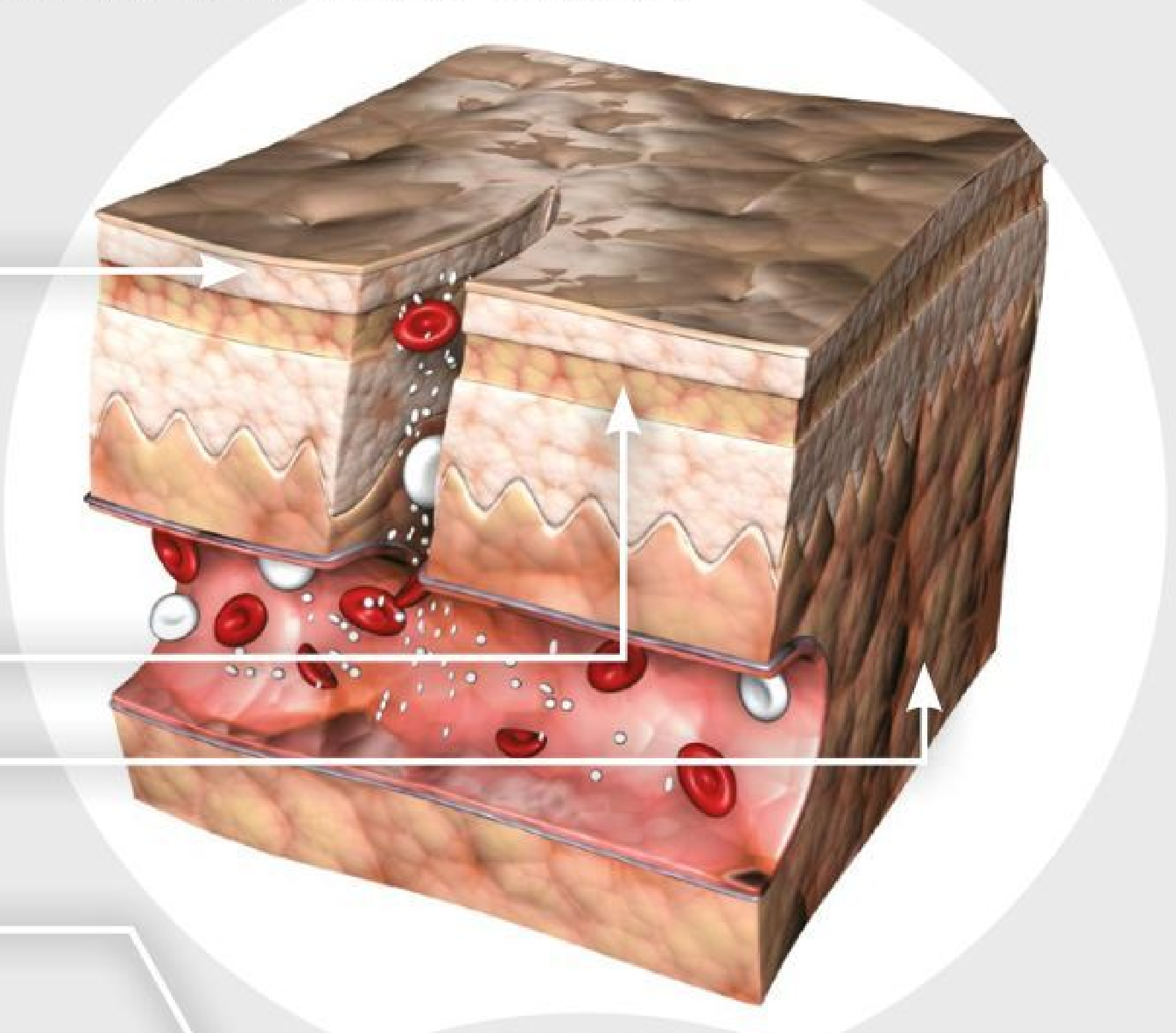
Rest
At rest the calf muscle is in its relaxed position.

Stretch
When the leg is bent or stretched the calf muscle will contract, and then relax when it is not.

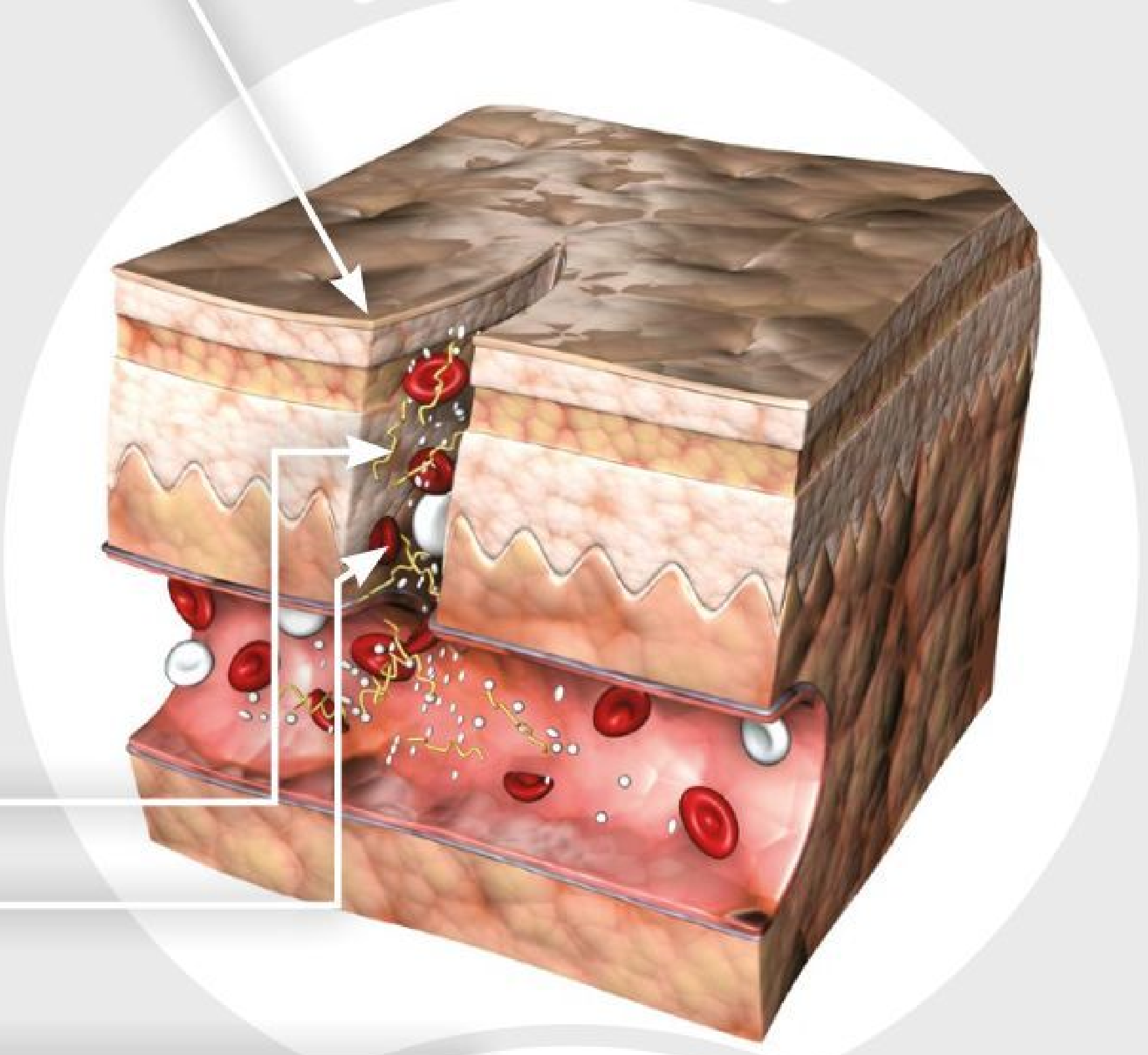
Cramp
Prolonged stretching of the leg prevents the calf muscle from relaxing, which can lead to cramp.

Formation of a blood clot

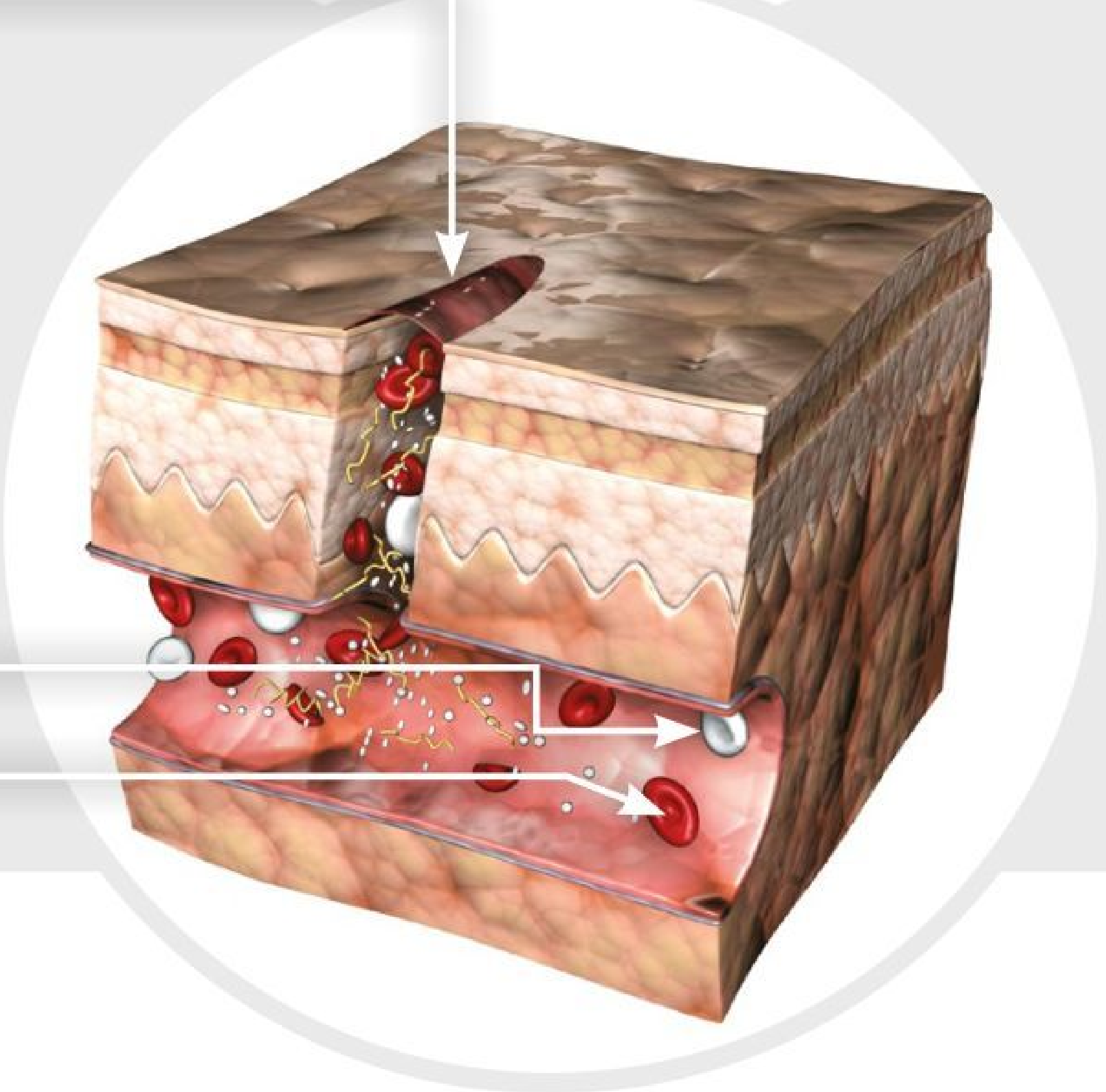
1. Skin layer
Composed of a water-resistant and protective layer called the epidermis; beneath it is the dermis layer that consists of blood vessels and connective tissue.



2. Cut
If skin is cut, platelets in the blood vessels of the damaged area become 'sticky' and clump together at the damaged site to form a white clot. Other chemical reactions create sticky web-like strands of fibrin that adhere to the damaged blood vessel wall, to form a red clot.



3. Healing
The blood clot stops blood escaping from the wound, and allows the normal circulation of the red blood cells which transport oxygen around the body and the white blood cells that protect it against infection.



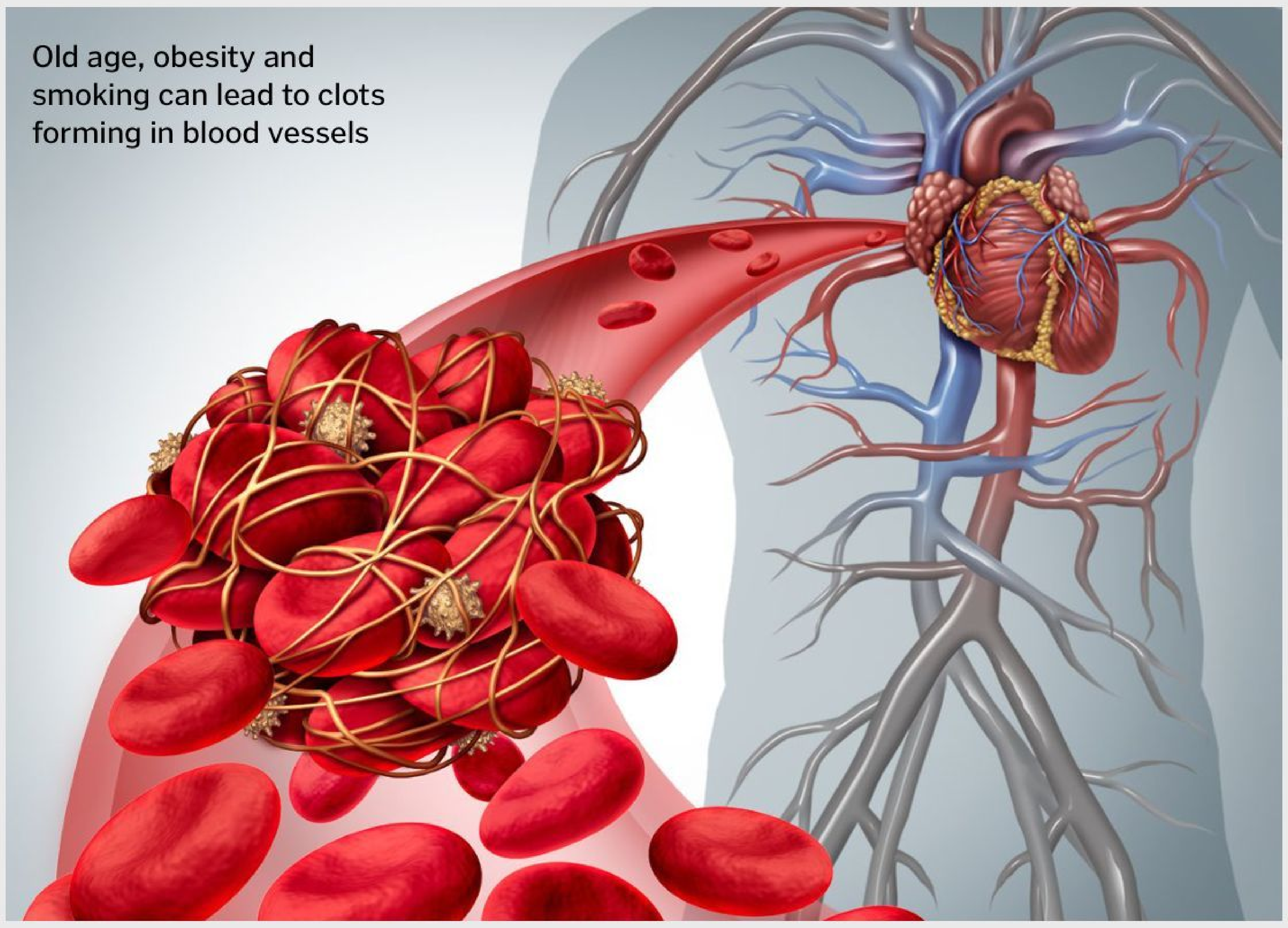
Blood clotting

How the body reacts to blood vessel damage to aid the healing process

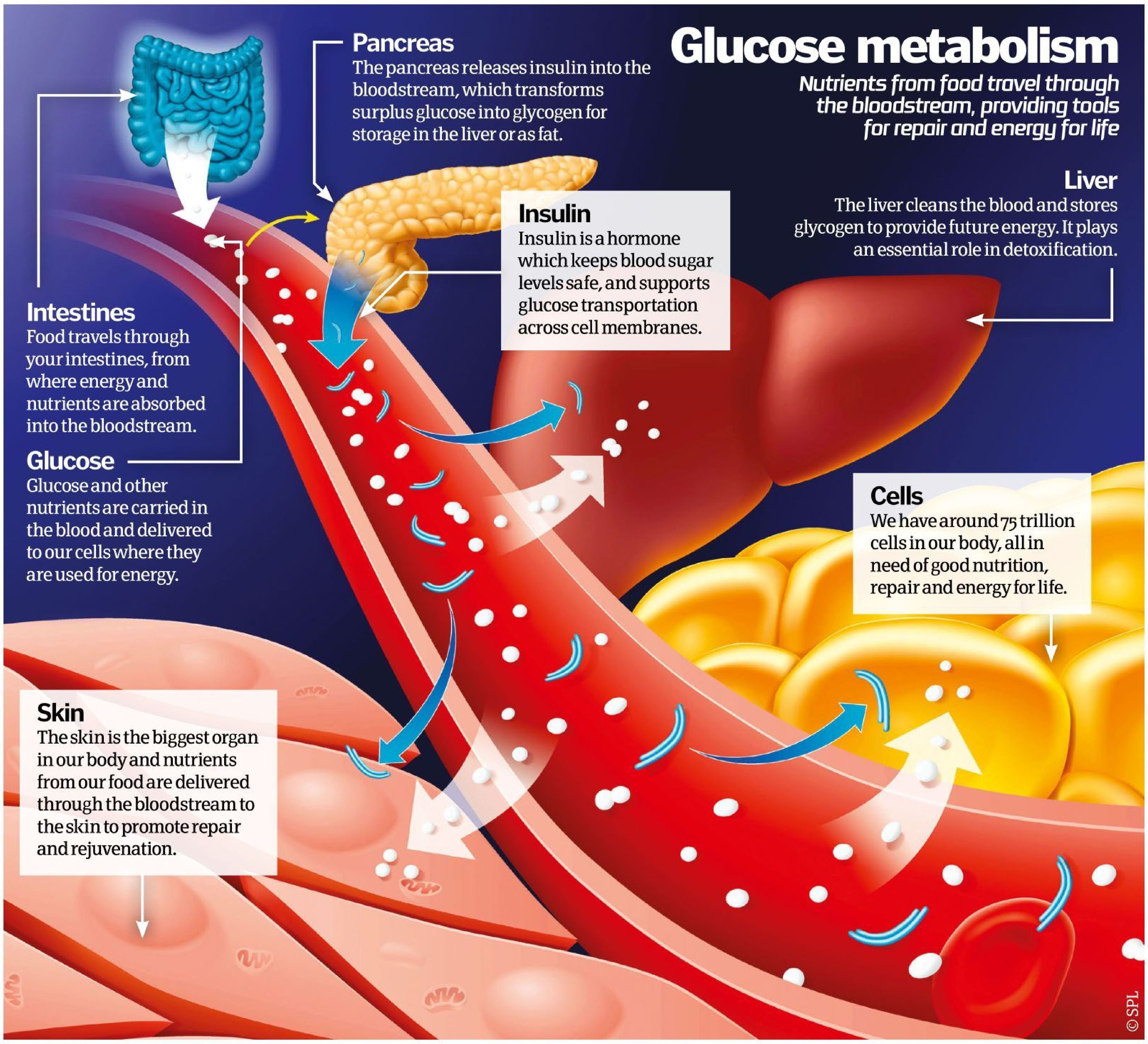
Through the action of the thrombin system, coagulation of the blood occurs instantly at the location where there is a cut or other injury to the skin. The blood clot, which consists of a combination of cellular platelets and sticky strings of fibrin, forms a plug in the damaged blood vessels.

The clot stops blood from freely flowing out of the body and at the same time allows the blood to continue circulating. As the skin heals, plasmin enzymes break down the webs of fibrin and the clot is eventually dissolved into the body.

Clots can also form in blood vessels due to inactivity, old age, obesity, smoking, poor diet or during pregnancy. This condition is known as thrombosis and can lead to an embolism.



Old age, obesity and smoking can lead to clots forming in blood vessels



Glucose metabolism

Nutrients from food travel through the bloodstream, providing tools for repair and energy for life

Pancreas
The pancreas releases insulin into the bloodstream, which transforms surplus glucose into glycogen for storage in the liver or as fat.

Liver
The liver cleans the blood and stores glycogen to provide future energy. It plays an essential role in detoxification.

Insulin
Insulin is a hormone which keeps blood sugar levels safe, and supports glucose transportation across cell membranes.

Intestines
Food travels through your intestines, from where energy and nutrients are absorbed into the bloodstream.

Glucose
Glucose and other nutrients are carried in the blood and delivered to our cells where they are used for energy.

Cells
We have around 75 trillion cells in our body, all in need of good nutrition, repair and energy for life.

Skin
The skin is the biggest organ in our body and nutrients from our food are delivered through the bloodstream to the skin to promote repair and rejuvenation.

© SPL

How fast is your metabolism?

Metabolism doesn't just affect your ability to gain or lose weight

The basal metabolic rate (BMR) measures how fast a person's body uses energy (in calories) while at rest. If you eat too many calories, the body will store the energy as fat for later use. Those with a low BMR burn fewer calories while at rest and will have a tendency to gain weight.

Hormones play a key role in metabolism – eg thyroxine is a hormone produced by the thyroid gland which affects the speed of metabolism. An overactive thyroid can result in energy being used too fast, resulting in hyperactivity and weight loss. The hormone insulin is released by the pancreas in response to elevated blood glucose – usually after meals. It pushes blood sugar into the cells and triggers an increase in anabolic activities.

It's common for people to blame a slow metabolism for their weight problems, but usually this is unsubstantiated and more likely a result of poor diet and lifestyle choices.

How metabolism functions

Metabolism is vital for life – if it stops, you die

Metabolism is a series of chemical reactions in the body, which convert the food we eat into the energy that we use for growth, movement and healing. Metabolic reactions occur simultaneously to keep us healthy.

Metabolism begins with plants and photosynthesis – the process whereby a plant absorbs energy from sunlight enabling it to create sugars from water and carbon dioxide. We eat the plants, taking in this energy as carbohydrates, which release glucose into the bloodstream to fuel the body. Digestive enzymes break protein from food down into its individual constituents, called amino acids. Fats are converted into fatty acids, and carbohydrates become sugars, all of which are slowly released into the bloodstream as part of the digestive process.

These nutrients enter the body's cells through the blood and are used either to power the body, build muscle and repair damage or are stored for later use. So the process of metabolism is the building up of tissues, muscle and energy stores and the breaking down of energy stores and fat to generate energy when it is required.

Anabolism (constructive metabolism) is all about building and storing: it supports the growth of new cells, the maintenance of body tissues and the storage of energy for use in the future.

The reverse is catabolism (destructive metabolism), which produces energy for cellular activity. Catabolism releases glucose, mostly from carbohydrates and stored fat, which provides energy to heat the body and enable movement on demand.

Your BMR can be raised with regular exercise

DID YOU KNOW? *The liver also produces proteins necessary for blood clotting and transporting nutrients around the body*

How does the liver detoxify?

Optimal performance of the liver is integral to preventing disease

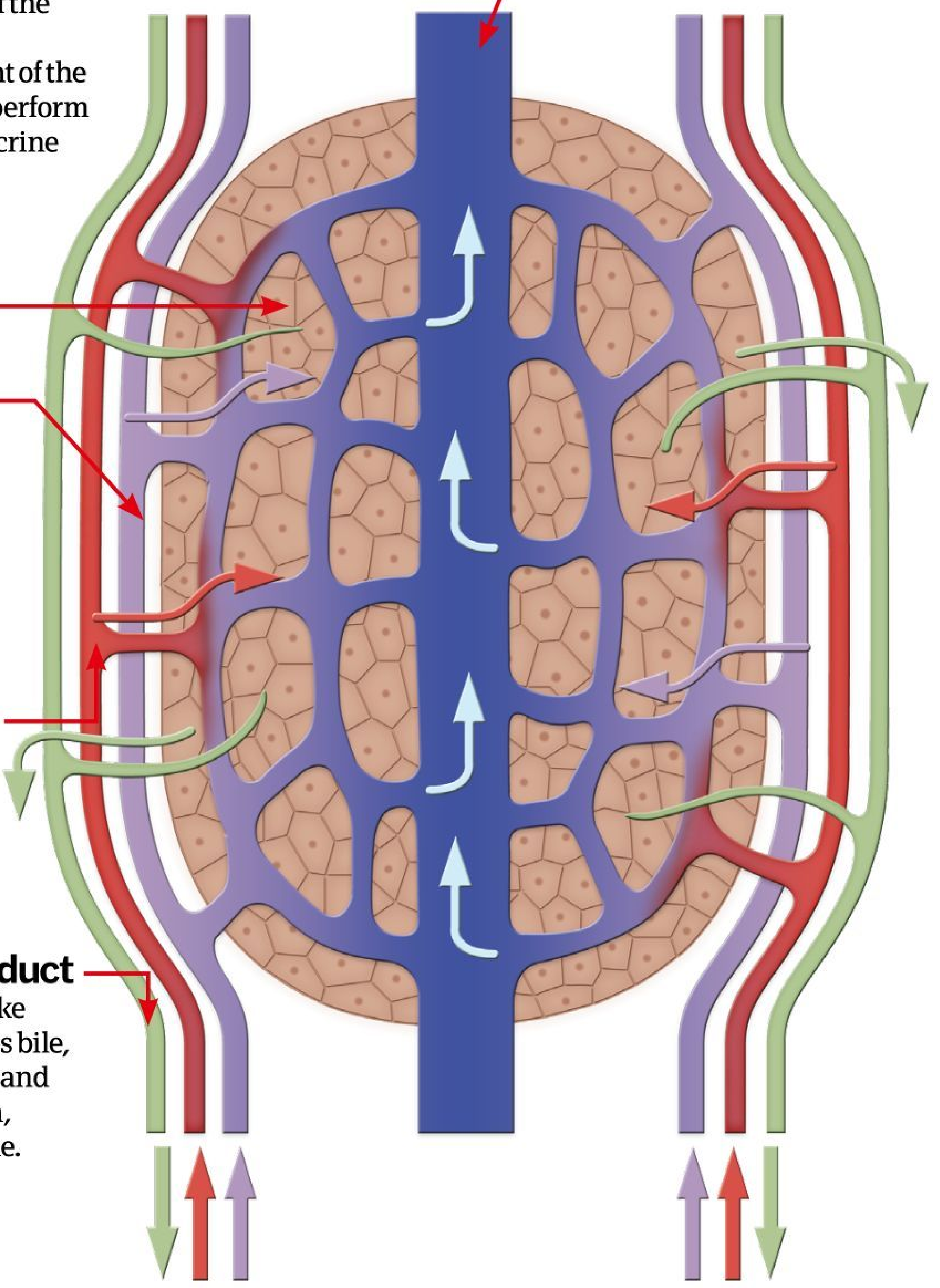
Toxins enter the body in food, water, through the skin and by inhalation. These toxins – such as pesticides, pharmaceutical drugs, chemicals and water-borne pollutants – end up in our bloodstream, and our liver filters the blood to remove them. Toxins are also created by biochemical reactions in the body. Toxins affect us in many ways, from drunkenness caused by alcohol to the side-effects of certain medication.

The liver transforms fat-soluble toxins into a water-soluble form. This enables them to be released through the kidneys for elimination in urine, or into bile for elimination through the colon. Enzymes chemically break down toxins which have been absorbed through the intestines. The toxins are either neutralised, or converted into a more chemically active form which is then neutralised, to be safely excreted.

A healthy liver will manufacture approximately one litre (1.75 pints) of bile per day to transport toxins out of the body. If the liver is sluggish, toxins can build up, causing inflammation and oxidative stress. Toxins which are not eliminated return to the bloodstream and are eventually stored in fatty tissues where they pose less of an immediate threat. In the longer term, however, the slow release of these toxins back into the bloodstream can lead to a number of diseases.

Toxins come in many shapes and sizes and must all be processed by the liver for excretion

A LIVER LOBULE CLOSE UP



Central vein
The central vein receives blood from the sinusoids and returns it to circulation via the hepatic vein.

Hepatocytes
Hepatocytes are the predominant cells of the liver, making up an estimated 80 per cent of the organ's mass. They perform metabolic and endocrine functions as well as detoxification.

Branch of portal vein
This vein delivers nutrient-rich blood for use by the hepatocytes.

Branch of hepatic artery
This artery delivers oxygen-rich blood for use by the hepatocytes.

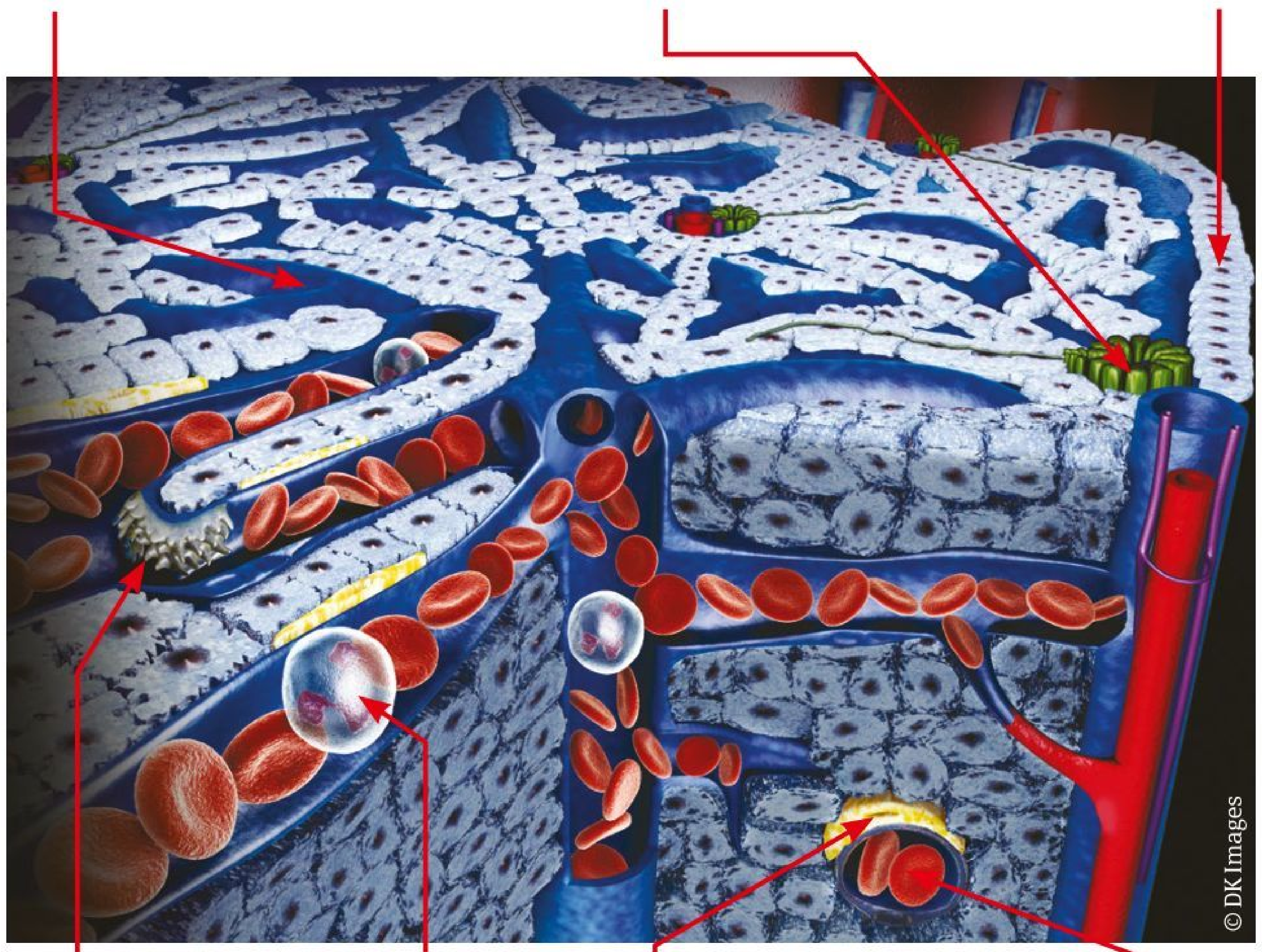
Branch of bile duct
This is a long tube-like structure that carries bile, secreted by the liver and needed for digestion, towards the intestine.

The liver at work

Sinusoid
This blood vessel carries nutrients and oxygen from the portal and hepatic arteries past the hepatocytes and back to the central vein.

Bile duct
Bile is largely produced by breaking down cholesterol, bile salts, water and bilirubin – which is a product of red blood cells.

Hepatocyte
Hepatocytes manufacture bile and secrete it into small channels which drain into the bile ducts.



© DK Images

Kupffer cell
Kupffer cells partly line the sinusoids and destroy microbes and dead cells.

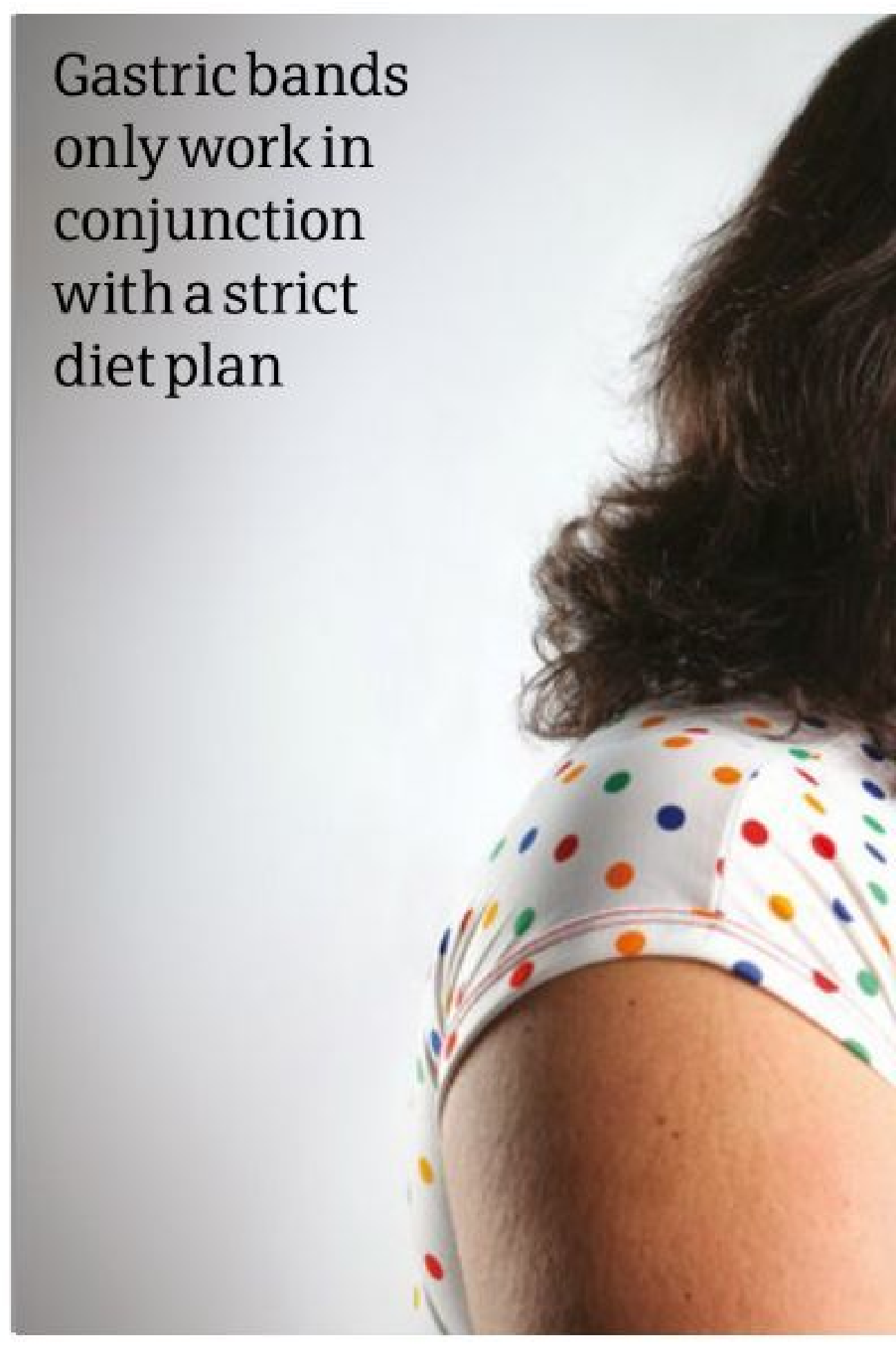
White blood cell
These cells are part of the immune system and help our bodies fight off infection.

Fat-storing cell
These cells contain fat which regulates local blood flow to the hepatocytes. They play a key role in repairing cells in the liver when they're damaged.

Red blood cell
These cells carry oxygen to the body's tissues. They contain iron-rich haemoglobin, which is the pigment that makes blood red.

How do gastric bands work?

Gastric bands aren't just for cosmetic purposes – they can help to prevent health problems too



Gastric bands only work in conjunction with a strict diet plan

Gastric bands are inflatable circular balloons that are placed around the top of the stomach. They reduce the total capacity of the sack-like organ, so when the patient eats, their stomach wall stretches sooner and tells their brain that they are full, but with a smaller volume of food. This leads to a lower daily calorific intake and, as part of a controlled diet and exercise regime, results in weight loss.

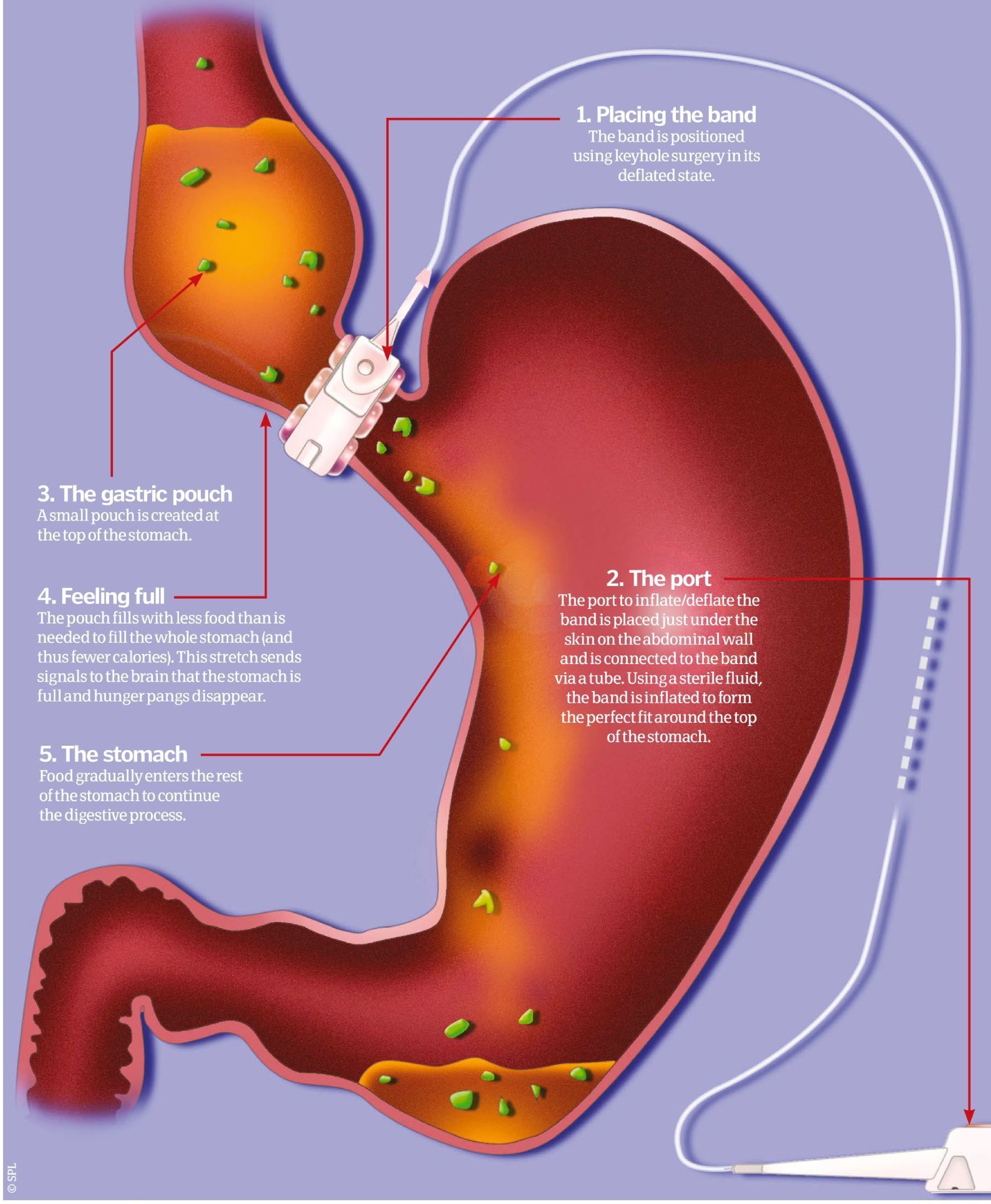
The band is typically placed with keyhole (or laparoscopic) surgery, leading to smaller scars, less pain and a shorter hospital stay. However, patients first need a vigorous workout. They must try and lose weight through conventional methods and medications, which may take up to six months. All patients undergoing weight-loss surgery must see a health psychologist too. The patients should be mentally prepared and positive that a gastric band will help them slim down as part of a holistic approach – for example, it won't work if they continue to eat pizza and chips at every meal!

The band is placed in position in its deflated state. Through a port placed just under the skin, its size can be adjusted incrementally, leading to a controlled rate of weight loss; uncontrolled, over-quick weight loss can be very dangerous.

As with any medical procedure, there are potential risks and complications. The band can slip or become too tight around the stomach, leading to pain and visits to the emergency department. In these circumstances, deflating the band through the port beneath the skin solves most problems in the short term.

> *"Over-quick weight loss can be very dangerous"*

GETTING THE PERFECT FIT



1. Placing the band
The band is positioned using keyhole surgery in its deflated state.

2. The port
The port to inflate/deflate the band is placed just under the skin on the abdominal wall and is connected to the band via a tube. Using a sterile fluid, the band is inflated to form the perfect fit around the top of the stomach.

3. The gastric pouch
A small pouch is created at the top of the stomach.

4. Feeling full
The pouch fills with less food than is needed to fill the whole stomach (and thus fewer calories). This stretch sends signals to the brain that the stomach is full and hunger pangs disappear.

5. The stomach
Food gradually enters the rest of the stomach to continue the digestive process.

© SPL

DID YOU KNOW? *The first adjustable gastric band was patented by Dr Dag Hallberg in Sweden in 1985*

How healthy are you?

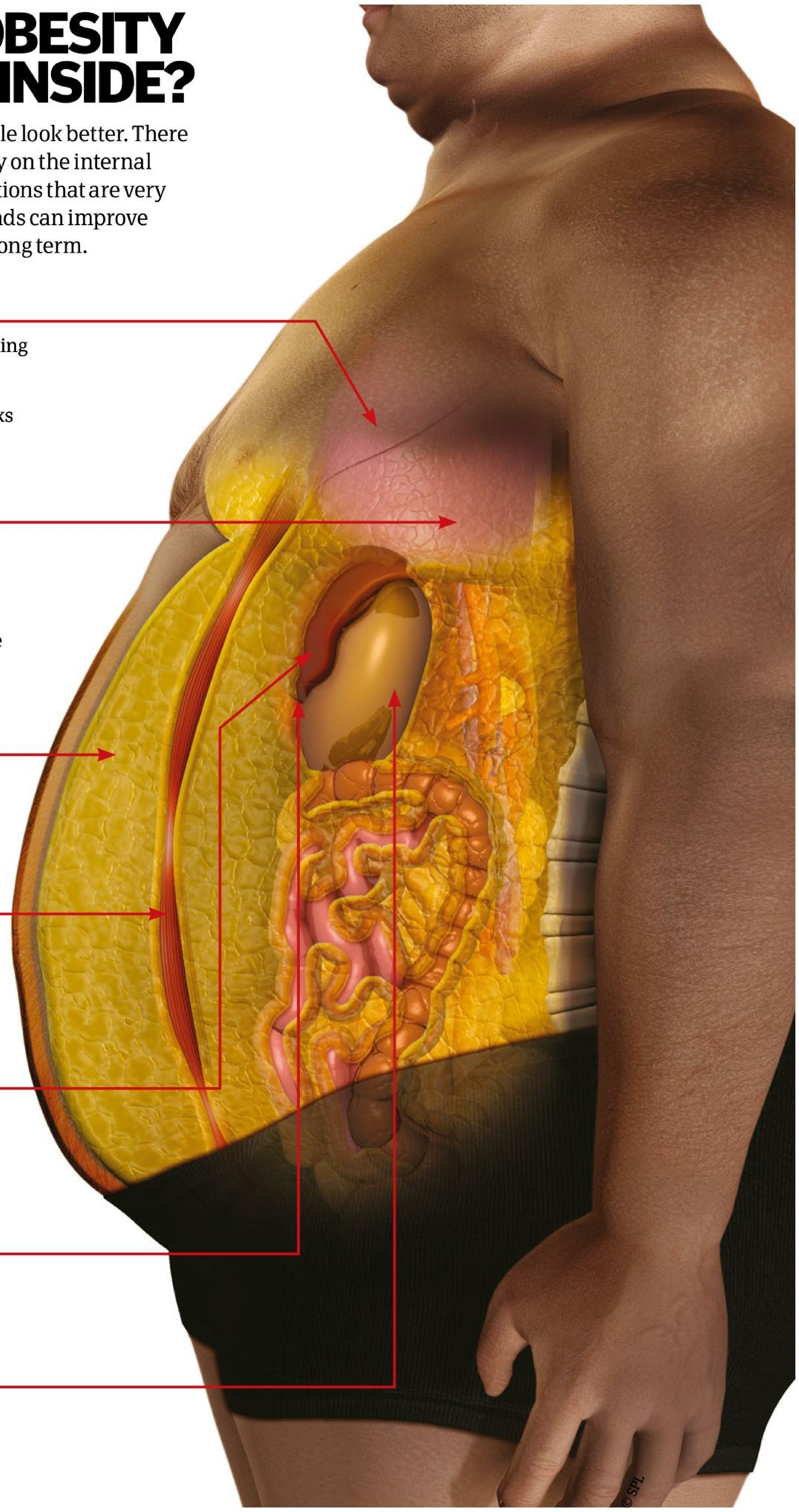
The body mass index (BMI) is commonly used to estimate a person's body fat. It is utilised around the globe, including by the World Health Organisation. It estimates a person's body size by dividing their weight by their height squared (ie BMI = weight in kilograms/ height in metres squared). The advantages are that it is easy to use, is the same for males and females and, in adults, is age independent. In children, it is used slightly differently and correct values vary according to age.

The BMI reading corresponds to categories of underweight, normal, overweight and obese. The disadvantage of the BMI system is that it doesn't take into account people's differing body proportions or muscle bulk. Athletes with lots of muscle, for example, would be classified as being overweight and thus unhealthy, although they're probably very fit. Some children who grow at different rates may be classed as outside normal ranges too, whereas they are in fact just in a growth spurt. That's why BMI must be used in conjunction with the person's overall fitness and appearance, and should be measured at several points over time to detect trends.

Prior to any surgery, patients must try and lose weight via non-invasive methods like exercise or drugs

HOW DOES OBESITY AFFECT YOU INSIDE?

Gastric bands don't just make people look better. There are serious consequences of obesity on the internal organs, which have health implications that are very expensive to treat. Thus gastric bands can improve health and be cost-effective in the long term.



© SPL

The heart
Obesity reflects underlying high-circulating triglycerides and poor health. This 'circulating fat' can block the coronary arteries, leading to angina or heart attacks (myocardial infarctions).

The lungs
When obese people have a layer of fat sitting on their chest wall, combined with fat from the abdomen preventing complete expansion of the lungs, it can lead to breathing problems. This is worse at night when lying flat and can cause sleep apnoea, where all breathing stops.

The abdominal wall
Everyone has a fatty layer on their abdominal wall. In obesity, this is often larger and it reflects what's going on inside too.

The muscles
Everyone has rectus abdominis (six-pack) muscles, even if they're buried between layers of fatty adipose tissue.

The liver
Obesity can lead to fatty liver disease (FLD), which in turn can progress to serious scarring of the organ (known as cirrhosis).

The pancreas
Obese people are at a higher risk of developing diabetes, which is related to changes within the pancreas.

The kidneys
High levels of circulating fats can block the arteries feeding the kidneys, causing hypertension. There are other effects on the kidneys too, although these are not fully understood as yet.

What's the alternative?

All patients should start with a regime of healthy eating and exercise before considering surgery. Medications should be tried next and, combined with the right lifestyle, most people will lose weight and regain their health. However, some people don't manage to lose weight, despite trying hard, so surgery is the only option left.

An alternative to the gastric band is the sleeve gastrectomy. During this procedure, most of the stomach is removed, leaving a sleeve-shaped tube. In a similar way to gastric bands, the patient feels full sooner, reducing the calorific intake. Gastric bands are not permanent and can be removed, but they can also slip out of place. Sleeve gastrectomies are permanent and won't dislodge, but the procedure is more invasive and there are other potential complications that will need to be discussed thoroughly with the surgeon.

During a gastric bypass, on the other hand, a small pouch of the stomach is created which is connected to the small intestine lower down. This has a malabsorption effect, which ultimately means that fewer calories from what is ingested are taken into the body.

There are other forms of intervention, such as intragastric balloons, but not enough evidence exists to assess them properly. Finally, abdominoplasty (a 'tummy tuck') is a quick way to get rid of some excess abdominal fat without changing anything inside; this is purely cosmetic surgery though and has no internal health benefits.

How skin grafts work

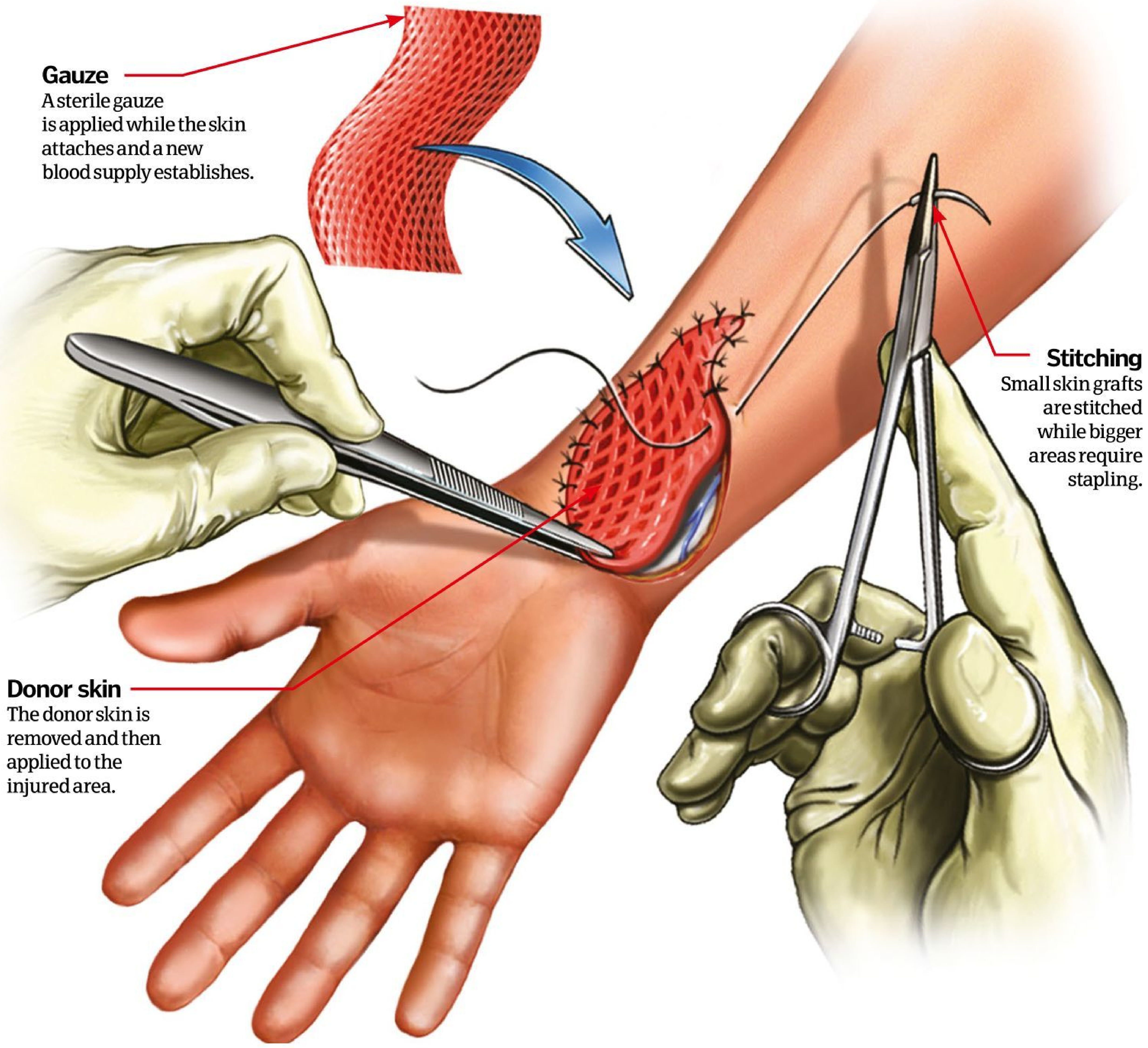
When our body's largest organ is damaged, sometimes it needs a helping hand to heal

Skin grafting is a medical procedure where a portion of skin is removed and stitched onto another part of the body. There are many cosmetic and medical reasons why this might be necessary: serious burns, surgery, tattoo removal and some medical conditions (skin cancer or diabetes, for example) might all necessitate skin grafting.

Autografts are skin grafts taken from the patient's own body, usually the buttocks, neck or back of the arm. Depending on the size of the area that it's removed from, it's then stitched or stapled closed again and the new skin applied to the injured area. Allografts and xenografts, meanwhile – taken from other humans and animals, respectively – are temporary grafts.

But perhaps most interesting is the artificial 'skin' called Integra, made of animal collagen that gives the damaged part an organic scaffolding for new skin to grow into. This is usually used in cases of extreme burns where there isn't enough healthy skin for an autograft.

Skin graft surgery



Gauze
A sterile gauze is applied while the skin attaches and a new blood supply establishes.

Stitching
Small skin grafts are stitched while bigger areas require stapling.

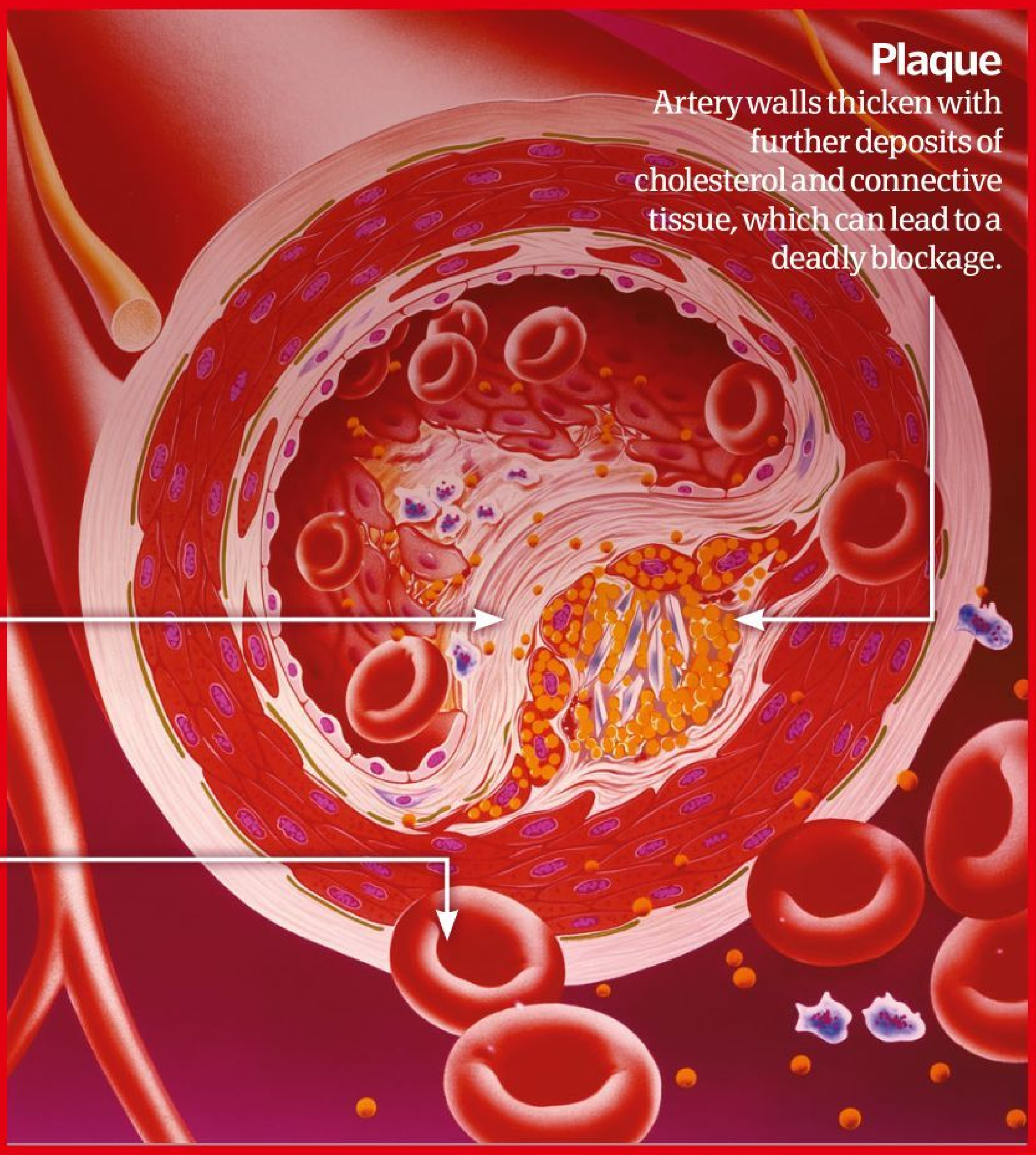
Donor skin
The donor skin is removed and then applied to the injured area.

© Alamy

Is cholesterol bad for you?

Is this substance as evil as we hear?

Cholesterol is a fatty molecule in the blood and, generally speaking, having too much is bad: it can stick to the walls of your arteries and increase the risk of heart disease. Most foods, with the exception of offal, eggs and shellfish, don't contain any cholesterol, but many contain saturated fats, which are turned into cholesterol by the liver. However, cholesterol itself isn't unhealthy – in fact, you wouldn't be able to live without it. The body uses cholesterol as a kind of padding, coating the outer membranes of all our cells and insulating nerve fibres, helping signals travel properly to and from the brain. It's also a fundamental part of the endocrine system, as all steroid hormones (eg oestrogen) are synthesised from cholesterol. A good diet and regular exercise can keep cholesterol within a healthy range for most people.



Artery wall
Wear and tear comes with age, and a diet high in saturated fat can lead to fatty buildup on artery walls.

Plaque
Artery walls thicken with further deposits of cholesterol and connective tissue, which can lead to a deadly blockage.

Blood
Restriction of blood flow in the arteries can lead to angina, strokes and heart attacks.

Hypermobile joints

Are super-bendy people simply more flexible than the majority of us, or is there a physiological explanation?

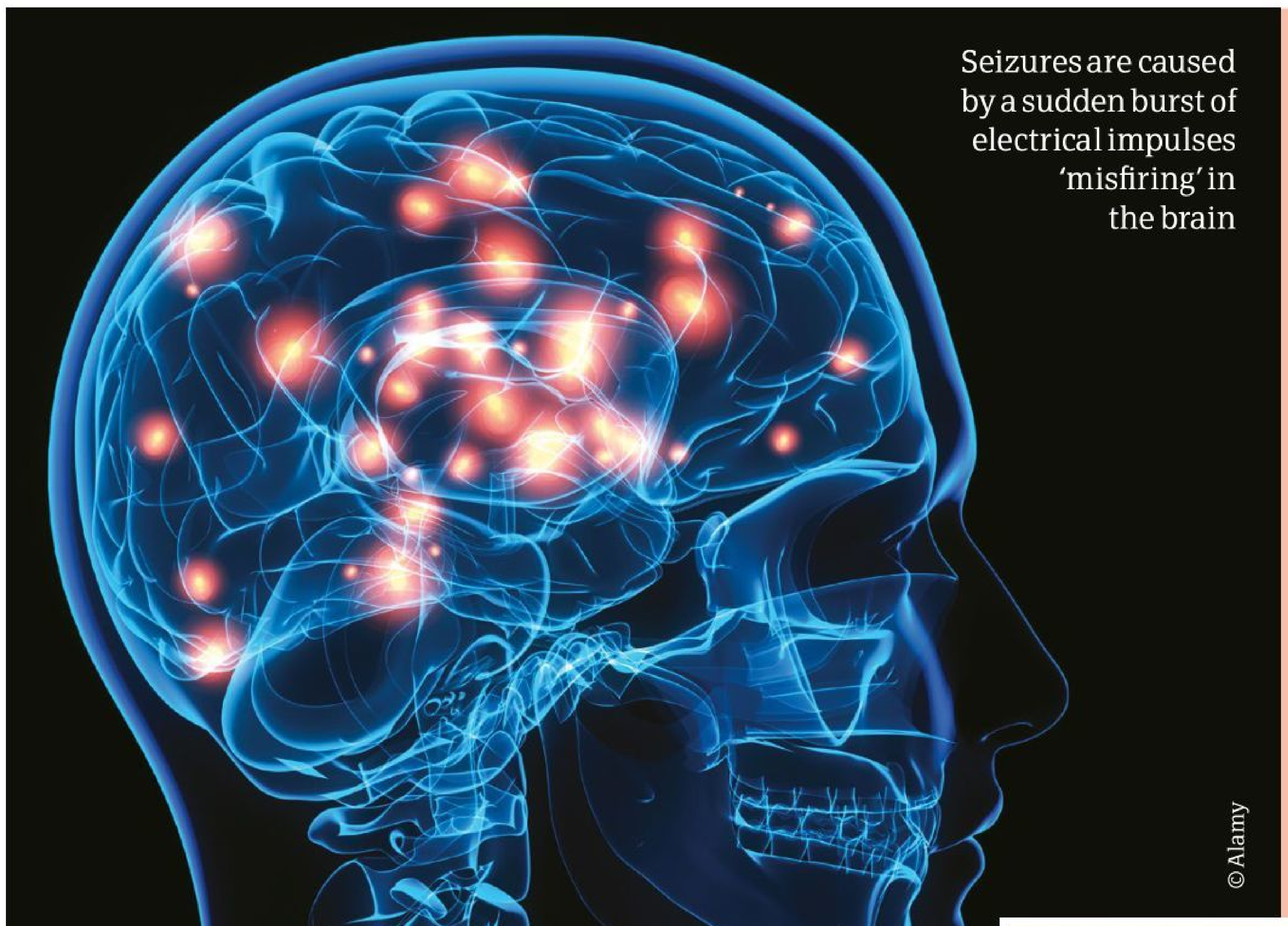
There's always one in a group: the 'double-jointed' person who can bend their thumbs back to touch their wrists, or wrap their legs behind their head. We often think of these people as especially flexible, and sometimes they are. But often hypermobile joints are indicative of an underlying medical condition.

Hypermobility syndrome (HMS) is a combination of genetic conditions that lead to muscles, tendons and ligaments that are formed differently, and are usually more fragile and prone to injury. Benign joint hypermobility syndrome (BJHS) can be considered a low level of hypermobility where 'bendy' joints can result in some pain but no life-threatening complications. Marfan syndrome, on the other hand, can be much more serious: in addition to limb dislocation, sufferers of the more serious form can experience problems with their vision, nervous system and potentially fatal heart problems, all as a result of weakened connective tissues.

Clinical diagnosis of hypermobility syndrome is made using the Beighton score, a nine-point criteria that requires the suspected HMS patient to attempt certain postures and thus confirm or rule out certain conditions. Treatment might include pain-killing drugs, although a high level of fitness and a healthy lifestyle will often help in milder cases.

It may make a cool party trick, but acts like this can indicate serious maladies

© SPL



Seizures are caused by a sudden burst of electrical impulses 'misfiring' in the brain

© Alamy

What is a fit?

Why do some people experience these violent bodily convulsions?

A fit, also known as a seizure or convulsion, is when abnormal electrical activity in the brain changes a person's behaviour. This can be caused by many things and take many forms, but the most common 'fit' is one caused by epilepsy. Injury to the brain, drug misuse, birth defects and other medical conditions can all result in epilepsy, which causes the brain to become excitable and its neurons to send out abnormal signals.

Symptoms depend on the part of the brain affected and can be as simple as a focal seizure which might result in eye rolling or muscle contraction, or as dramatic as a 'grand mal'. In the latter, the entire body can experience violent muscle contractions and clenched teeth for several minutes. Sometimes the fit can halt breathing and leave the victim with a blue pallor, making them potentially life threatening.

Seizures are sometimes preceded by distinct tastes, sounds or smells, called auras, and can have a number of triggers, including stress, fever and, in some epileptic cases, flashing lights like strobes.

Drugs are often used to control epileptic fits

Epilim Syrup
EPISTATUS

Why do we get angry?

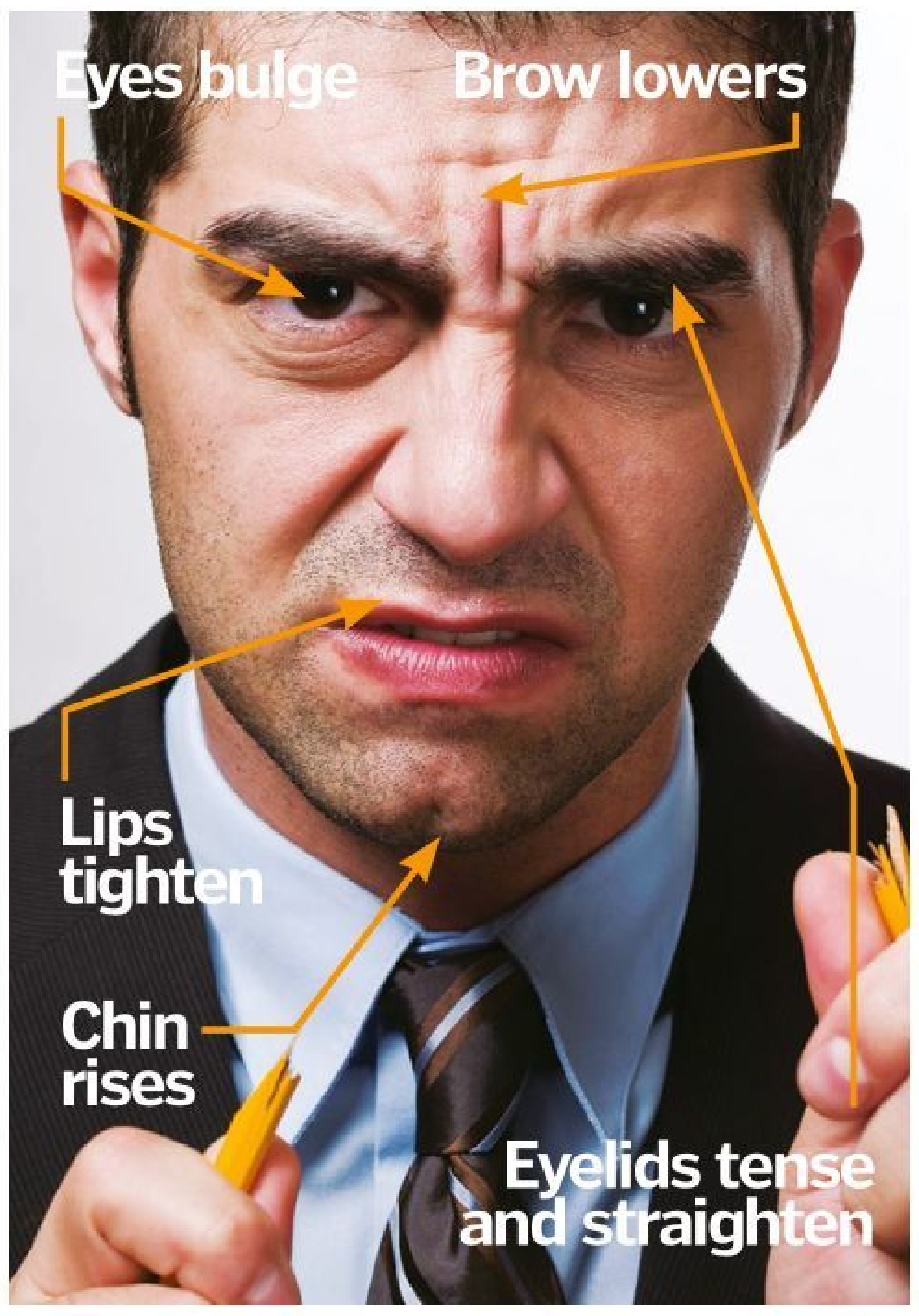
Learn what happens when someone loses it…

Anger is one of the six universal emotions experienced by humans – the others being happiness, fear, sadness, disgust and surprise. Our emotions are the largely unconscious physical responses we have to stimuli.

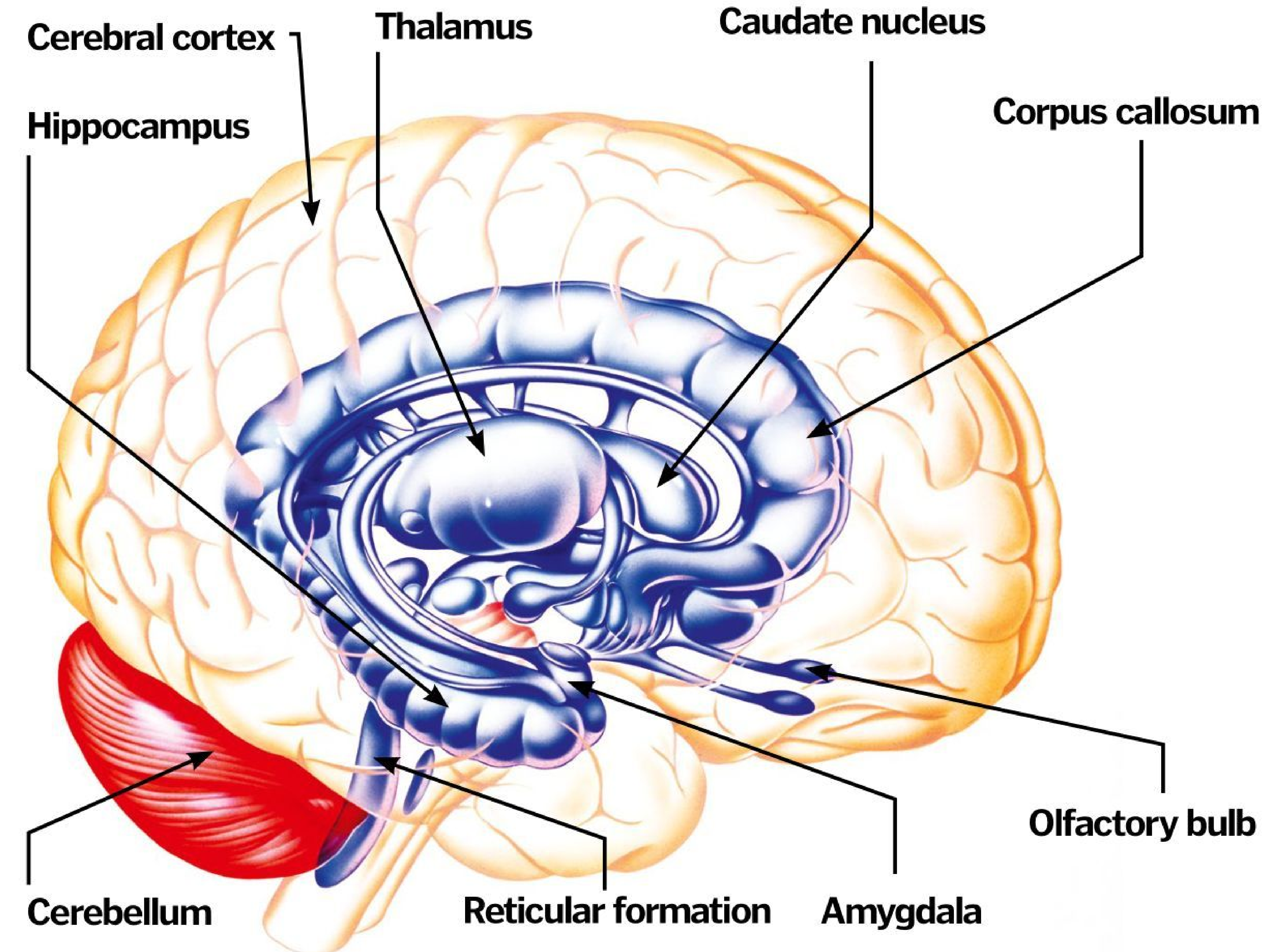
While we use the cerebral cortex in the brain to think logically and make judgements, anger is controlled by the limbic system, a group of structures buried lower down in the primitive regions of the brain. A sophisticated network of nerve pathways controls instinct and governs such emotions as fear and rage. We get angry to protect ourselves from danger if something threatens us, our belongings or anyone that we care about.

Within the limbic system is the amygdala, a structure in which we store our emotional memories. Anger is a primitive form of self-preservation and it's the limbic system that invokes our natural instincts such as the fight-or-flight response to fear. When a stimulus triggers the amygdala, a flood of hormones – such as adrenaline – is produced automatically to warn the body to prepare for action. Because anger is controlled by the emotional centre of the brain – rather than the 'thinking' part – an angry person can temporarily lose control of their actions as well as the things they say. This is why we often refer to someone as 'losing it' when they get really mad.

We exhibit anger in a variety of ways, including facial expressions, raising of the voice and more aggressive behaviour. We communicate this emotion for others to read and respond to.

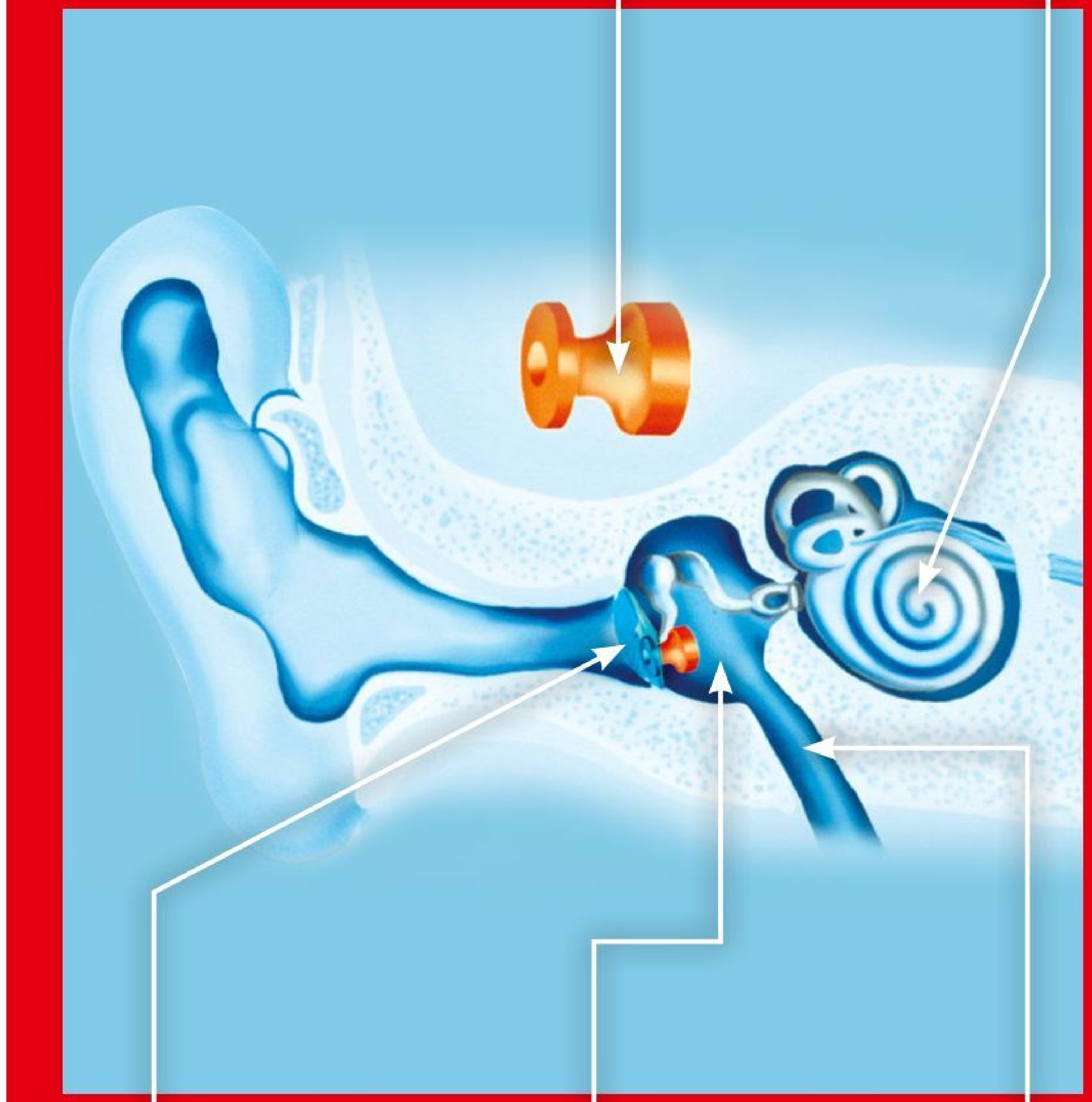


Exploring the limbic system



What are grommets?

Why are these little plastic tubes often used to clear blocked ears?



Grommet
The grommet is a tube around 1.5mm (0.06in) in diameter, inserted into a tiny incision in the eardrum.

Inner ear
This contains the cochlea, which receives sound pressure from the eardrum, plus the vestibular system, which deals with balance.

Eardrum
Otherwise known as the tympanic membrane, it's used to transmit sounds to the middle ear.

Middle ear
Otitis media is a common infection, or inflammation, that occurs in this part of the ear.

Eustachian tube
Made of bone and cartilage, this tube is prone to infection via the nose and throat.

The Eustachian tube runs from the back of your nose to your middle ear and helps fluid drain away as well as maintain a pressure equilibrium, allowing the eardrum to vibrate as it should. Infection can block the Eustachian tube and cause a partial vacuum in the middle ear, which in turn will lead to a fluid buildup and potentially temporary hearing loss.

Mild infections may clear up with time or can be treated with antibiotics. But with more serious or reoccurring infections, an operation called a myringotomy may be considered. This procedure involves cutting into the eardrum and inserting a grommet, which will release the fluid and essentially allow the middle ear to 'breathe'. The grommet itself is a tiny piece of tube about the size of a match head. It allows the inflamed ear to recover, after which the eardrum itself will push the grommet out after six months or so and heal over.

© Thinkstock; SPL

Anaphylactic shock

Learn about this potentially life-threatening condition and what can bring it on

Anaphylaxis, otherwise known as anaphylactic shock, is a potentially deadly allergic reaction. It can be brought on by any number of conditions, but it's usually triggered by ingesting food that the person is allergic to – such as nuts, eggs or shellfish, being stung by an insect, or coming into contact with a particular drug or chemical. Signs someone is experiencing anaphylaxis include respiratory difficulties, dizziness, red rashes and other skin changes, plus a form of subcutaneous swelling called angioedema.

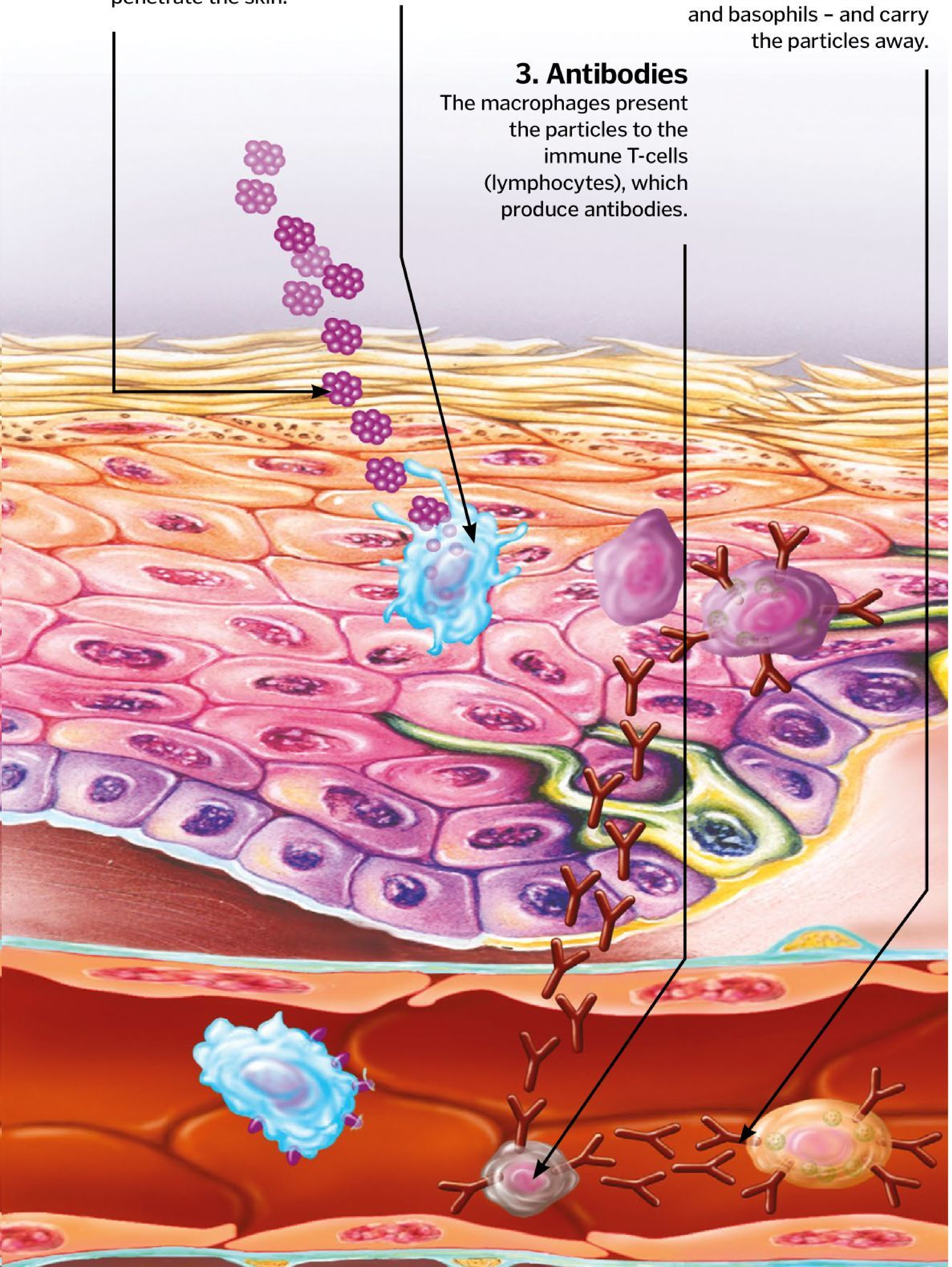
Anaphylaxis is essentially an overreaction to a toxin, such as wasp venom, or a bad reaction to a substance that the body perceives as a threat. When the substance (known as an allergen) enters the body through the skin, inhaled into the lungs or ingested through the mouth, the reaction between the allergens and the immune system's antibodies releases a number of chemicals from cells in the blood and tissue. This includes histamine, which causes swelling in the contact area, although it can spread to the whole of the body depending on the severity of the reaction.

Blood pressure falls and breathing can be restricted, especially if the swelling is around the throat. In asthmatics, the allergic effect takes place in the lungs, which is why an asthma attack is particularly dangerous.

Treating anaphylaxis

Anaphylactic shock can be serious, especially if it's undiagnosed. Fortunately most people are aware of their allergies and can avoid the foods or substances that cause a reaction. Asthmatics, for example, have an inhaler for when they feel an asthma attack coming on. In emergencies, an auto-injector device is used to shoot adrenaline into the thigh. The adrenaline counteracts the symptoms of the reaction by constricting blood vessels, which raises blood pressure, opens up the airways and suppresses the release of histamine. The patient usually sees a very rapid improvement once the adrenaline has been administered, although they will generally require supervision in hospital for a day or two to ensure the allergens are out of their system.

Normal reaction



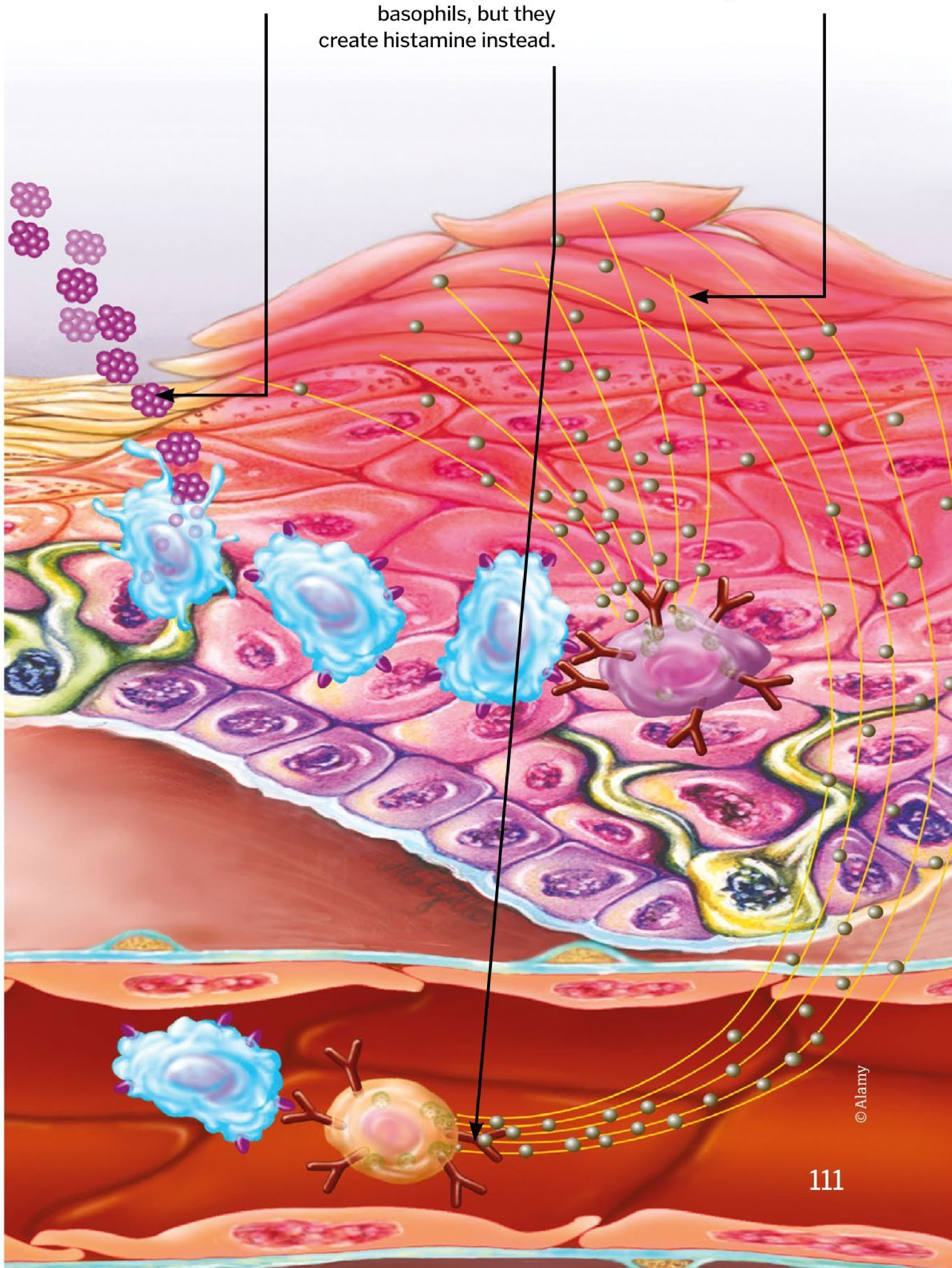
1. Contact
In the case of a wasp sting, or skin contact allergy, the allergens penetrate the skin.

2. Macrophages
The macrophages ingest the allergens and bring them into the bloodstream.

3. Antibodies
The macrophages present the particles to the immune T-cells (lymphocytes), which produce antibodies.

4. Immune specialists
The antibodies attach themselves to immune specialists – mastocytes and basophils – and carry the particles away.

Allergic reaction



1. Contact
As before, the allergens penetrate the skin and the allergic reaction begins.

2. Histamine
The allergic antibodies produced attach to the mastocytes and basophils, but they create histamine instead.

3. Angioedema
The histamine produced results in excessive swelling in the area.

© Alamy

Brain surg

Discover one of the most challenging of all medical specialties. If you thought rocket scientists had to pay attention to detail, wait until you meet this lot…

There is still so much we don't know about the human brain. However, if something goes wrong and it needs an operation, you will find yourself in need of a neurosurgeon. These guys can operate on the vast number of structures within the brain and spinal cord, and have a full arsenal of techniques and – literally – cutting-edge technologies to hand.

A neurosurgeon's workload comes in two main forms. The emergency work is often a result of road traffic accidents or fights, and often affects young men with head injuries. These patients may have bleeding within the skull, which is exerting pressure on the brain – the neurosurgeon must relieve that pressure. There is also the planned work, where neurosurgeons try to remove tumours with meticulous detail to surrounding structures.

The technology starts a long way before the operation. Advanced CT and MRI scans allow for 3D reconstructions and images that we couldn't have even dreamed of a few years ago. This allows neurosurgeons to plan the precise timing and nature of surgery – where to cut and how deep to make the incision. The imaging falls within a team approach to caring for these patients, as the team is just as important as the technology.

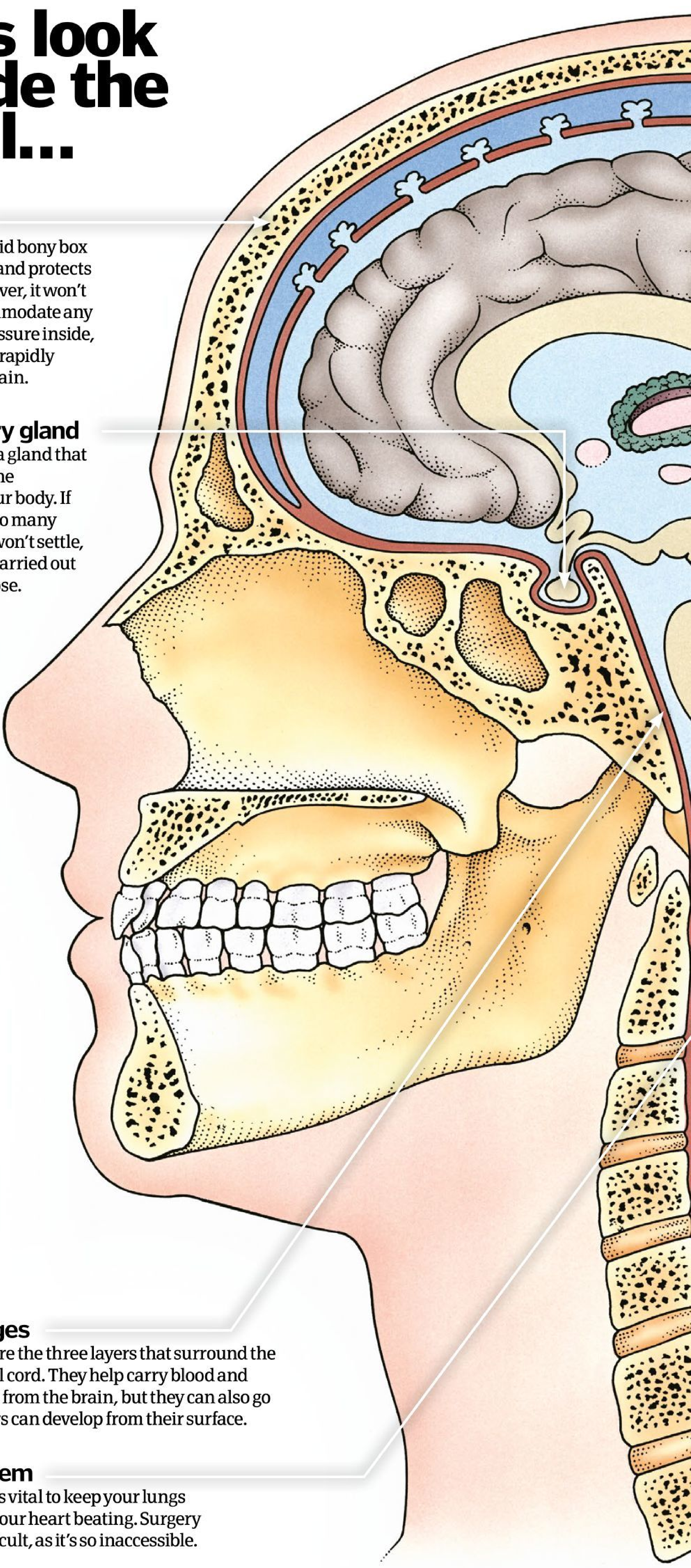
Surgery is becoming less invasive as time goes on. The advantages of this are smaller incisions, less disruption to surrounding tissues, less pain and shorter hospital stays. Surgeons now often use powerful microscopes with bright lights to help them remain as precise as possible. These microscopic techniques require a huge amount of skill, dexterity and hand-eye co-ordination that would impress even a fighter pilot.

New neuro-navigation techniques and robotic surgery can

Famous American neurosurgeon Sanjay Gupta at work

© US Navy

Let's look inside the skull…



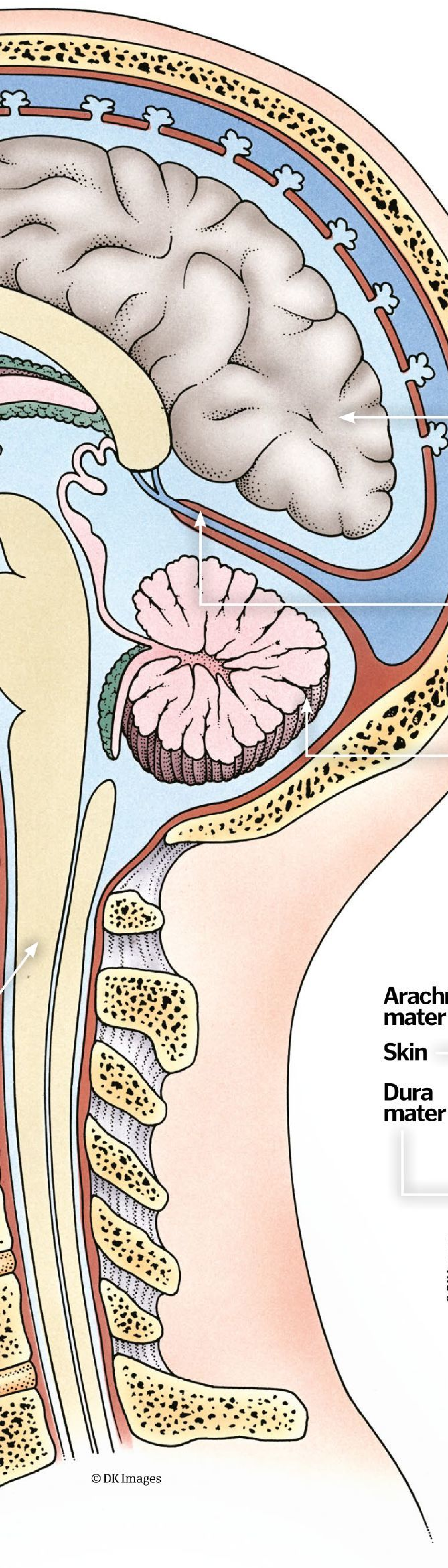
The skull
The skull is a rigid bony box that surrounds and protects the brain. However, it won't stretch to accommodate any increases in pressure inside, so bleeding can rapidly compress the brain.

The pituitary gland
The pituitary is a gland that helps regulate the hormones in your body. If it's producing too many hormones and won't settle, surgery can be carried out on it… via the nose.

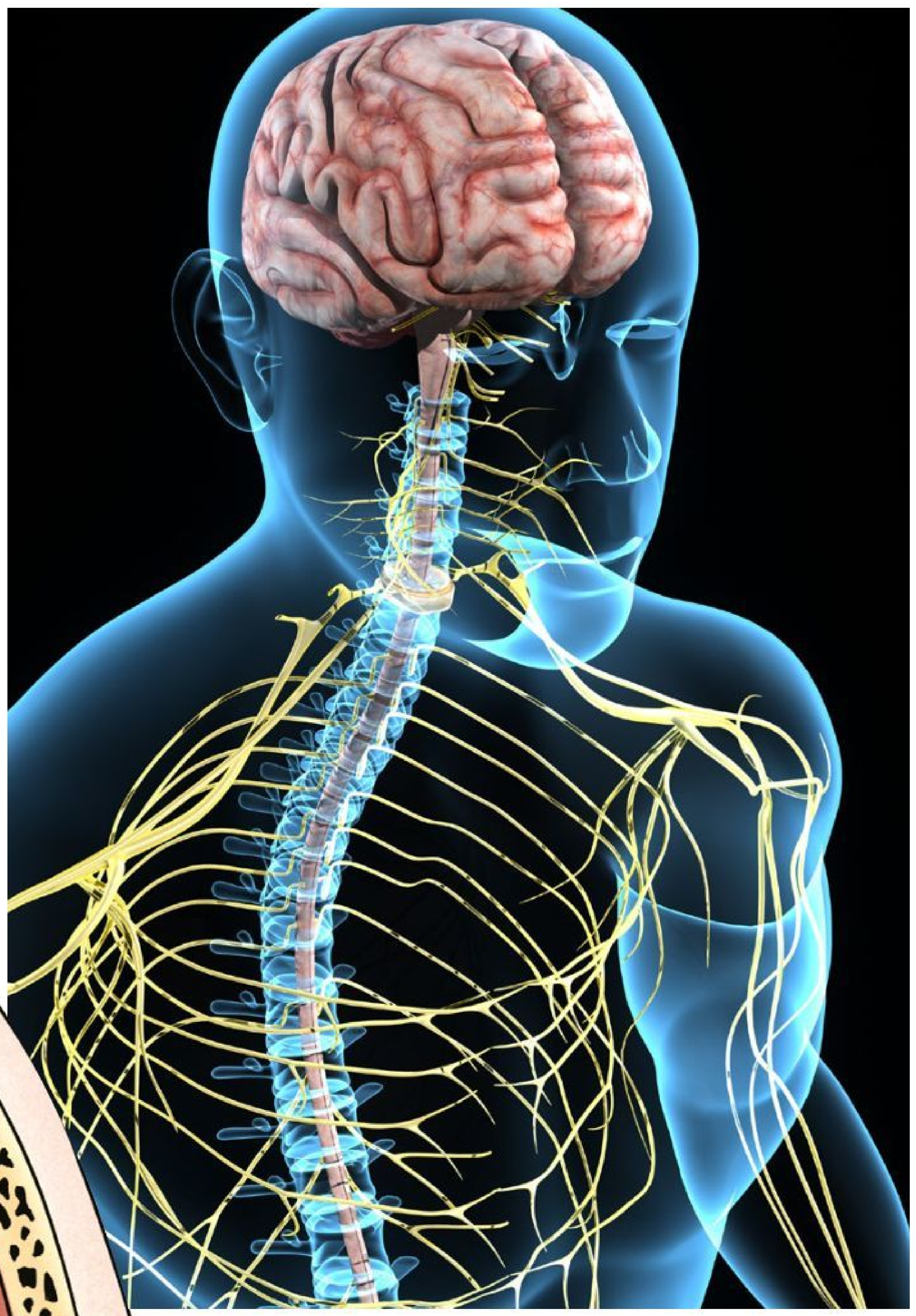
The meninges
The meninges are the three layers that surround the brain and spinal cord. They help carry blood and nutrients to and from the brain, but they can also go wrong – tumours can develop from their surface.

The brainstem
The brainstem is vital to keep your lungs breathing and your heart beating. Surgery here is very difficult, as it's so inaccessible.

ery



© DK Images

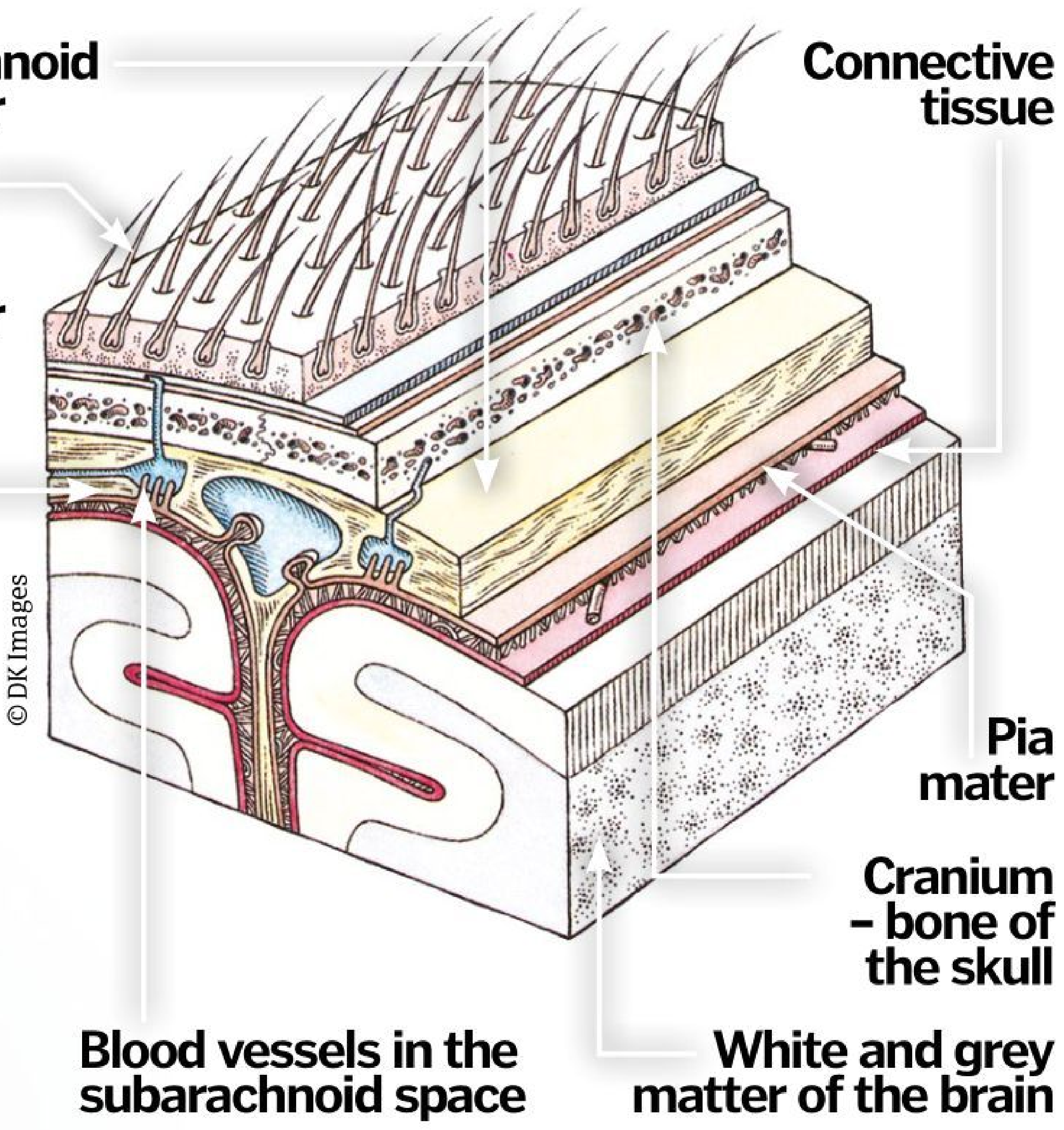


The grey matter
The grey matter contains complex areas of memory, personality and function. Surgery here can have few effects, or it can have devastating effects, such as taking away your memories or changing your personality.

The ventricles
The ventricles allow a special fluid – cerebrospinal fluid – to circulate around the brain. If they get blocked, the brain can swell rapidly and the pressure causes headaches as the meninges stretch.

The cerebellum
The cerebellum controls your fine movements. Surgery here can leave you with balance problems.

Layers surrounding the brain


Arachnoid mater
Skin
Dura mater
Connective tissue
Pia mater
Cranium – bone of the skull
Blood vessels in the subarachnoid space
White and grey matter of the brain

© DK Images

> *"Advanced CT and MRI scans allow for 3D reconstructions and images that we couldn't have even dreamed of a few years ago"*

Why do you need brain surgery?

Some of the common reasons for performing brain surgery

Trauma

Often following road traffic accidents or fights, head injuries are common – especially in young men. They can range from minor to life-threatening. Sometimes surgery won't help, but if the bleeding can be stopped in time, you need a neurosurgeon.

Appropriate procedure: Craniotomy
Procedure length: 1-4 hours
Recovery time: Weeks to months
Effectiveness of procedure: If early enough, completely effective. If late, it can be devastating.
Severity of condition: ■■■■■ **Difficulty of surgery:** ■■■□□

Tumours

Brain tumours present themselves in a variety of ways – some people have headaches, some have co-ordination problems, and some have no symptoms at all. Metastatic tumours, where growth is from another source (such as breast or bowel), are the most common type.

Appropriate procedure: Craniotomy or stereotatic surgery
Procedure length: 2-12 hours
Recovery time: Weeks
Effectiveness of procedure: Ranges from no effects to severe effects.
Severity of condition: ■■■■■ **Difficulty of surgery:** ■■■■□

Cerebral aneurysms

Swellings in the fine blood vessels within the brain can burst, leading to life-devastating bleeding. Preventing the bleeding is the trick here.

Appropriate procedure: Endovascular coiling
Procedure length: 1-3 hours
Recovery time: Days
Effectiveness of procedure: If coiled before a major bleed, it's likely to provide an excellent outcome.
Severity of condition: ■■■■□ **Difficulty of surgery:** ■■□□□

Epilepsy

Surgery for epilepsy isn't for everyone. In some cases, where medicines can't control the fits, surgery may be appropriate if the fits are arising from one area.

Appropriate procedure: Temporal lobectomy
Procedure length: 2-4 hours
Recovery time: Days
Effectiveness of procedure: 95% chance of success in selected patients.
Severity of condition: ■■□□□ **Difficulty of surgery:** ■■■□□

Parkinson's disease

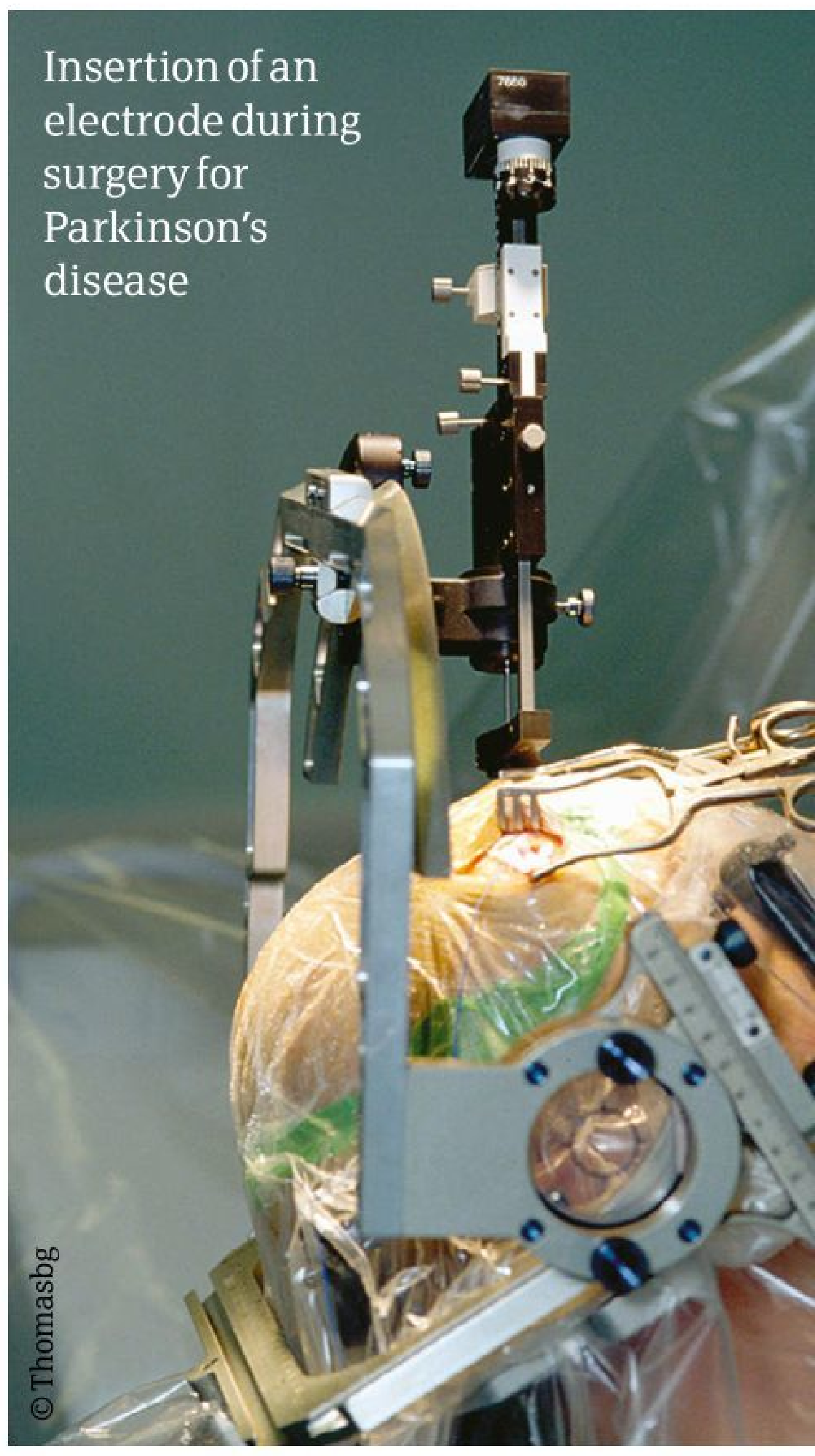
Some patients with Parkinson's disease will benefit from some extra stimulation of their nerves. Implanting a special nerve 'pacemaker' isn't easy, but this deep brain stimulation can produce stronger signals.

Appropriate procedure: Deep brain stimulation
Procedure length: 2-4 hours
Recovery time: Days
Effectiveness of procedure: Medium to good.
Severity of condition: ■■■□□ **Difficulty of surgery:** ■■■■□

help brain surgeons get to the hard-to-access places, which previously would have been inaccessible. Special scanning cameras and computers are used during the operation and are matched to a pre-existing scan to guide the surgeon's hand – much like the satellite navigation systems used by drivers. Neuro-endoscopy, which involves the use of tiny cameras to access the brain, is opening up many new opportunities in brain surgery. Incredibly, it's possible to access the brain via a tiny cut in the back of the nose, too.

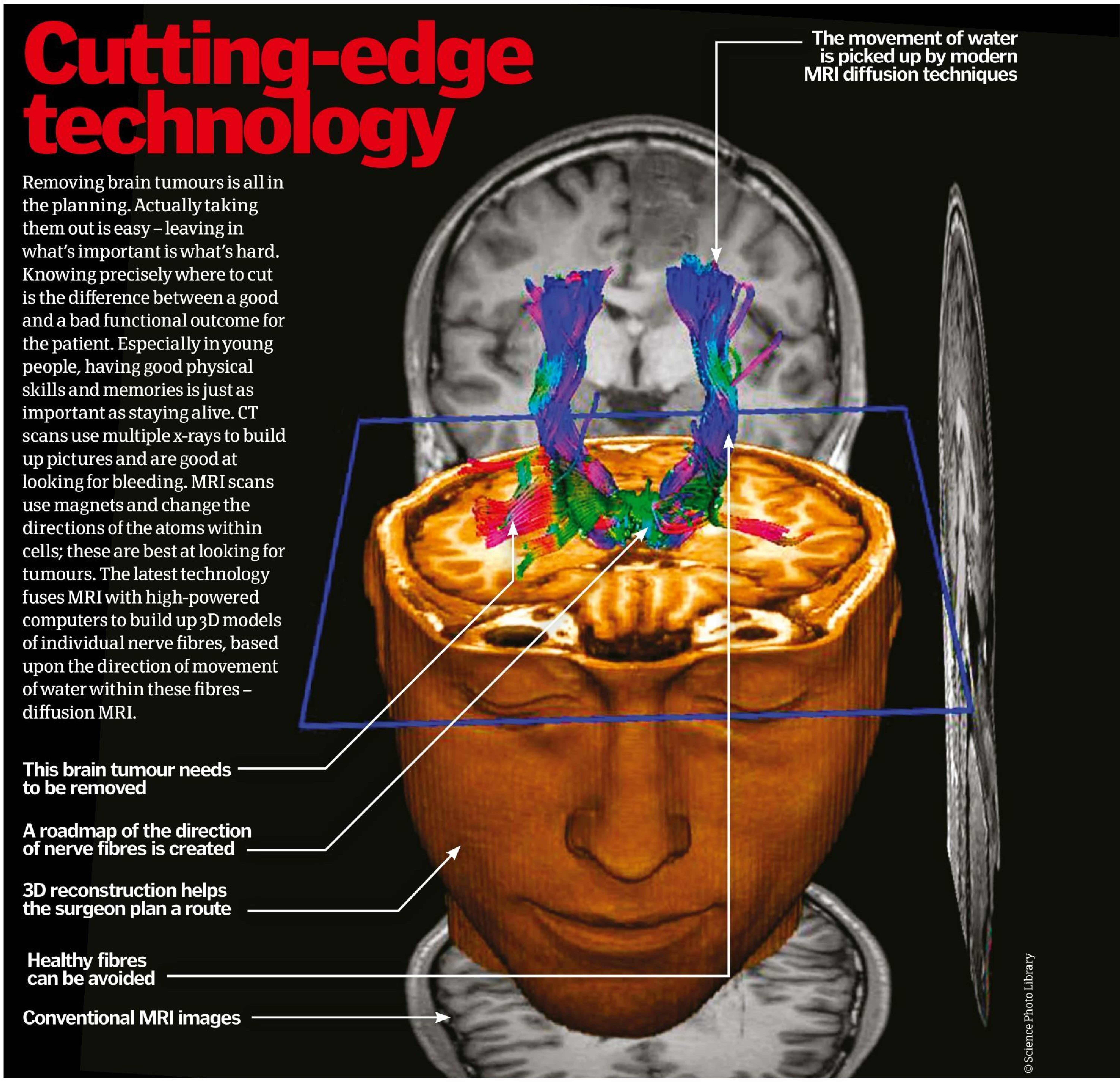
The brain is the network hub of the human body, co-ordinating all of the sensations we feel and then providing instructions for the complex movements we perform. Although it receives all of the pain signals from the body, the brain itself doesn't have pain receptors. This means that there is potential for neurosurgery to be carried out with the patient awake. However, there are pain receptors in the skin, muscles and linings that surround the brain, so it certainly isn't for everyone and it isn't performed everywhere.

Incredibly, there are bits of your brain that you can survive without – and you might not even notice any difference. It really depends on which part of the brain is removed – if you were to remove even a small part of the brainstem, for example, you would die instantly. On the other hand, removing or cutting larger parts of the main brain can leave just a few effects, such as memory problems. However, these discoveries were often made at the peril of surgeons operating and experimenting on patients in years gone by, which are now lessons confined to the history books.


Insertion of an electrode during surgery for Parkinson's disease

© Thomasbg

Cutting-edge technology


Removing brain tumours is all in the planning. Actually taking them out is easy – leaving in what's important is what's hard. Knowing precisely where to cut is the difference between a good and a bad functional outcome for the patient. Especially in young people, having good physical skills and memories is just as important as staying alive. CT scans use multiple x-rays to build up pictures and are good at looking for bleeding. MRI scans use magnets and change the directions of the atoms within cells; these are best at looking for tumours. The latest technology fuses MRI with high-powered computers to build up 3D models of individual nerve fibres, based upon the direction of movement of water within these fibres – diffusion MRI.

The movement of water is picked up by modern MRI diffusion techniques

This brain tumour needs to be removed

A roadmap of the direction of nerve fibres is created

3D reconstruction helps the surgeon plan a route

Healthy fibres can be avoided

Conventional MRI images

© Science Photo Library

The right tools for the job…

Discover the equipment used by brain surgeons

© Marvin 101 2009

Guglielmi detachable coil

These platinum wires are fed into small aneurysms (enlarged arteries) within the brain via an artery in the groin. Once coiled up inside the aneurysm sac, they stop blood flow and thus prevent bleeding.

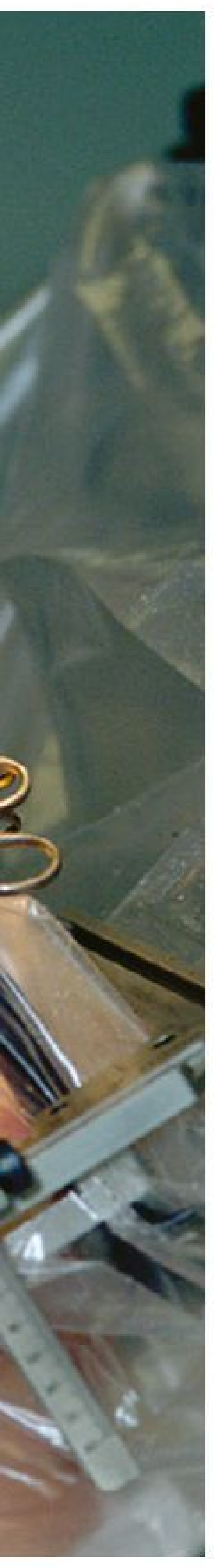
Surgical microclamps

These small clamps can be used to grab tumours to help the surgeon dissect them away from surrounding structures.

High-performance microscope

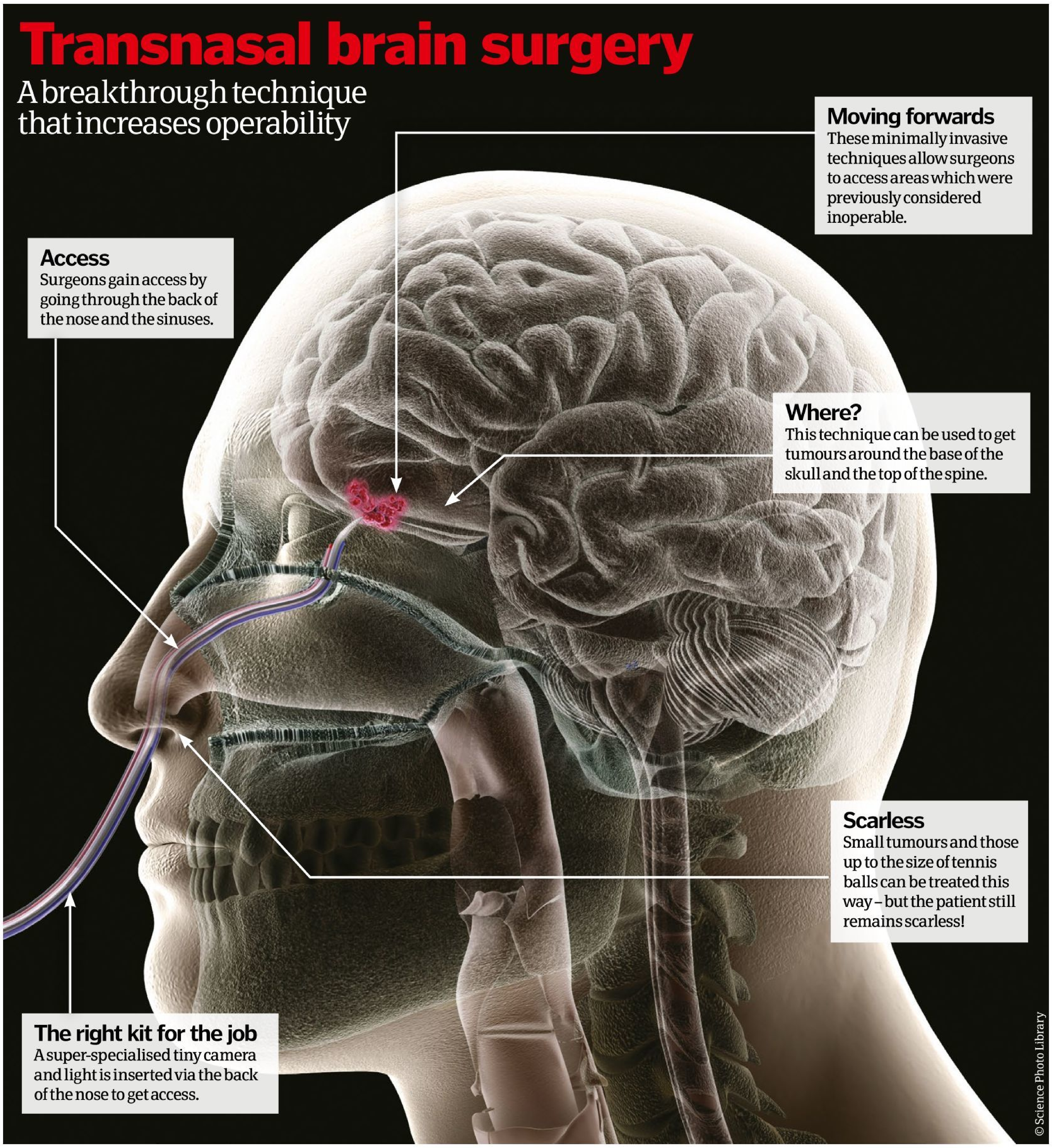
These powerful microscopes with bright lights enable surgeons to operate through tiny incisions or keyholes, which prevents damage to those important surrounding structures.

DID YOU KNOW? *Parkinson's patients can have tiny stem cells transplanted into their brains to stimulate new neurone growth*



Transnasal brain surgery

A breakthrough technique that increases operability



Moving forwards
These minimally invasive techniques allow surgeons to access areas which were previously considered inoperable.

Access
Surgeons gain access by going through the back of the nose and the sinuses.

Where?
This technique can be used to get tumours around the base of the skull and the top of the spine.

Scarless
Small tumours and those up to the size of tennis balls can be treated this way – but the patient still remains scarless!

The right kit for the job
A super-specialised tiny camera and light is inserted via the back of the nose to get access.

© Science Photo Library

Time critical!

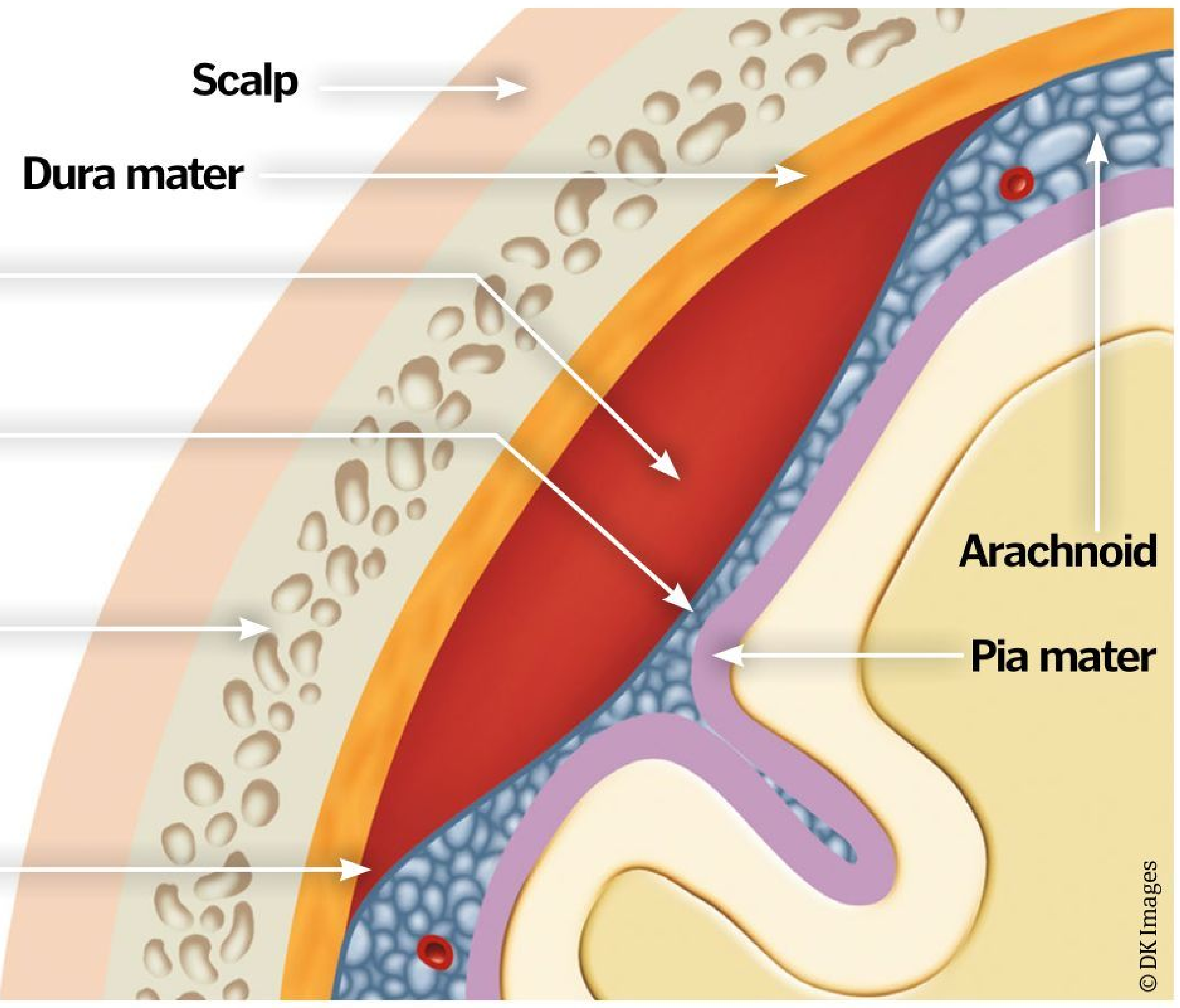
A haemorrhage needs urgent attention to save a life

Clot
A blood vessel has broken, forming a clot (haematoma).

Under pressure
The clot is causing increased pressure within the skull, squeezing the brain.

Skull
Since the skull is rigid, the brain is forced downwards towards the only exit – into the spinal column. This rapidly leads to death unless treated, as it damages the vital brainstem.

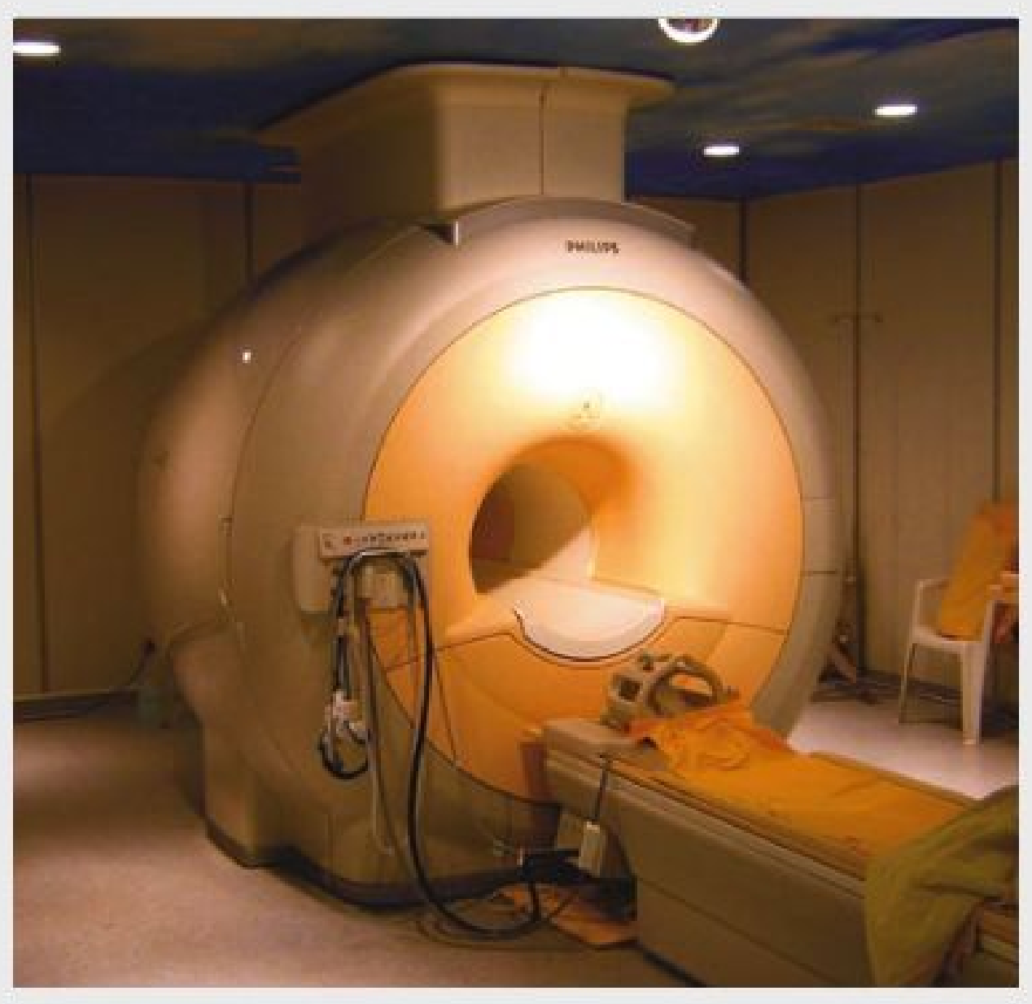
Life-saving
In true life-saving surgery, a surgeon will cut away a small piece of skull (craniotomy), clear away the clot and stop the bleeding.



© DK Images

The right tools for the job…

Discover the equipment used by brain surgeons



Navigation systems

This computer system merges pre-operative CT and MRI scans with intra-operative information gathered from lasers and infrared. The result is a 'map', which surgeons use to navigate to difficult-to-find tumours.

Burr-hole drill

Although not used much any more in the Western world, a drill is used to evacuate blood clots which form around the brain following accidents. They are still used in some parts of the world.

Haemostat

A vital surgical tool, a haemostat is a scissor-shaped device used to control bleeding. They are locked in place via a series of interlocking teeth, which can be varied according to the amount of pressure needed.

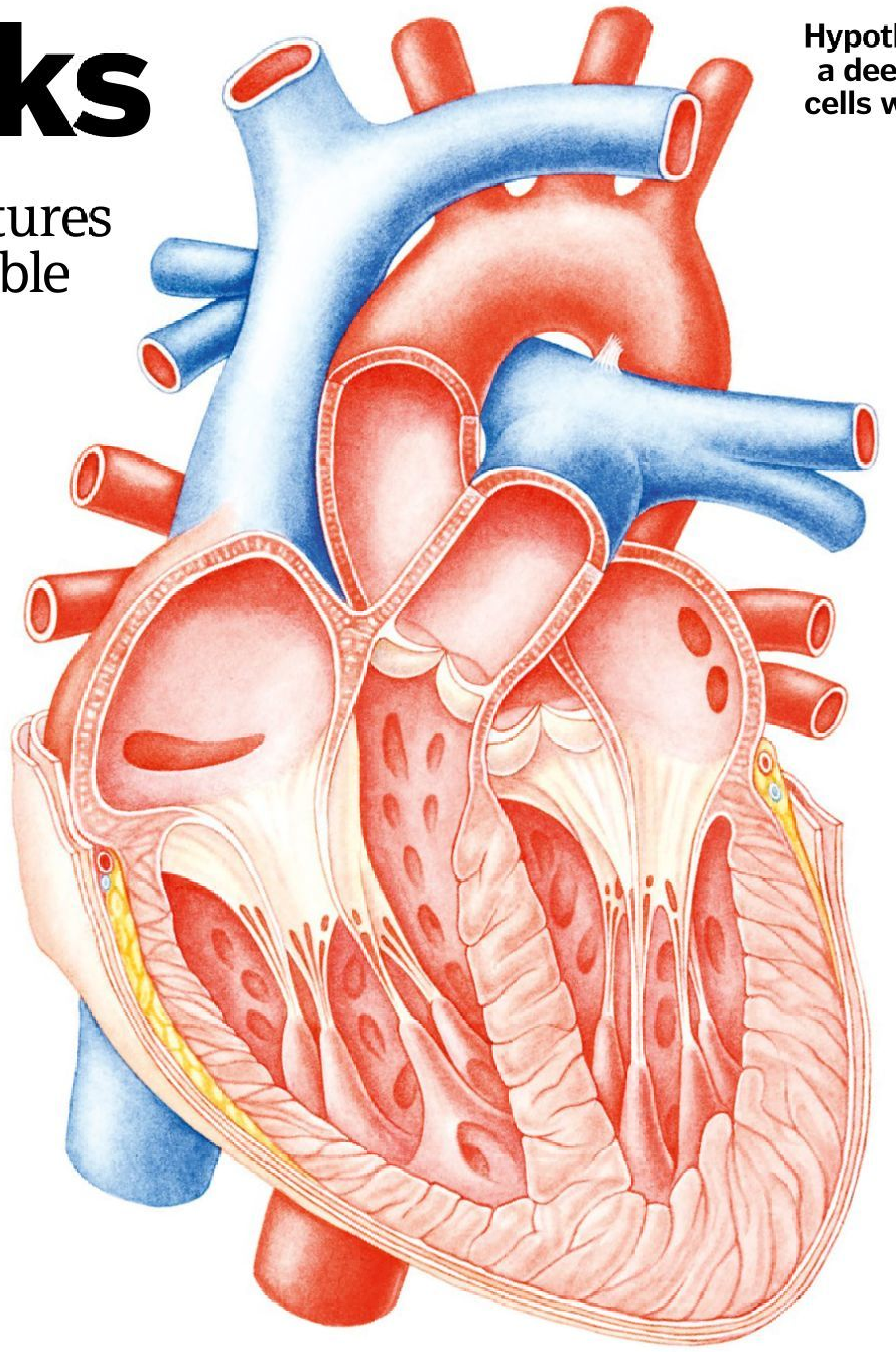
How hypothermic surgery works

Cooling the body to extreme temperatures makes cutting-edge procedures possible

During cardiac surgery, the heart will sometimes need to be stopped to allow surgeons to perform delicate procedures, such as replacing valves. If left uncorrected, the subsequent lack of oxygen supply would lead to brain damage within minutes. Cardiopulmonary bypass can overcome most of these effects, although it is technically not possible in all patients.

Hypothermic cardiac surgery can now be used to overcome these limitations. The body is cooled from its normal 37 degrees Celsius (98.6 degrees Fahrenheit) to as low as 24 degrees Celsius (75.2 degrees Fahrenheit). Cold saline solutions are infused into the bloodstream via the major vessels and the heart is surrounded by ice. This stabilises cell membranes and reduces the metabolic rate. Once cool enough, the heart is stopped using a potassium-rich solution. In this reduced oxygen-dependent state, the body can temporarily survive without the heart beating.

When surgery is completed, the potassium solution is rinsed out and the body re-warmed before the heart is restarted. Hypothermic cooling isn't without its risks, though; there is a chance that once a procedure is finished and the body re-warmed, the heart might not restart.



Super-cold surgery step-by-step

Hypothermic surgery requires a deep understanding of how cells work at a molecular level

1. Cooling
Using cold saline solutions infused into the circulation and ice placed around the heart, the body's core temperature is reduced.

2. Cardioplegia
A potassium-rich solution is used to paralyse the heart muscles – a process known as cardioplegia.

3. Cell membrane
The cold temperature stabilises ion transfer across cell membranes in the body, protecting them from the low-oxygen state.

4. Warming up
Once surgery is done, the body is re-warmed slowly. The cells start to re-function as oxygen returns to them.

5. Jump-start
The crucial moment comes when defibrillators are placed against the heart's muscular wall and an electrical current is used to shock it back to a beating state.

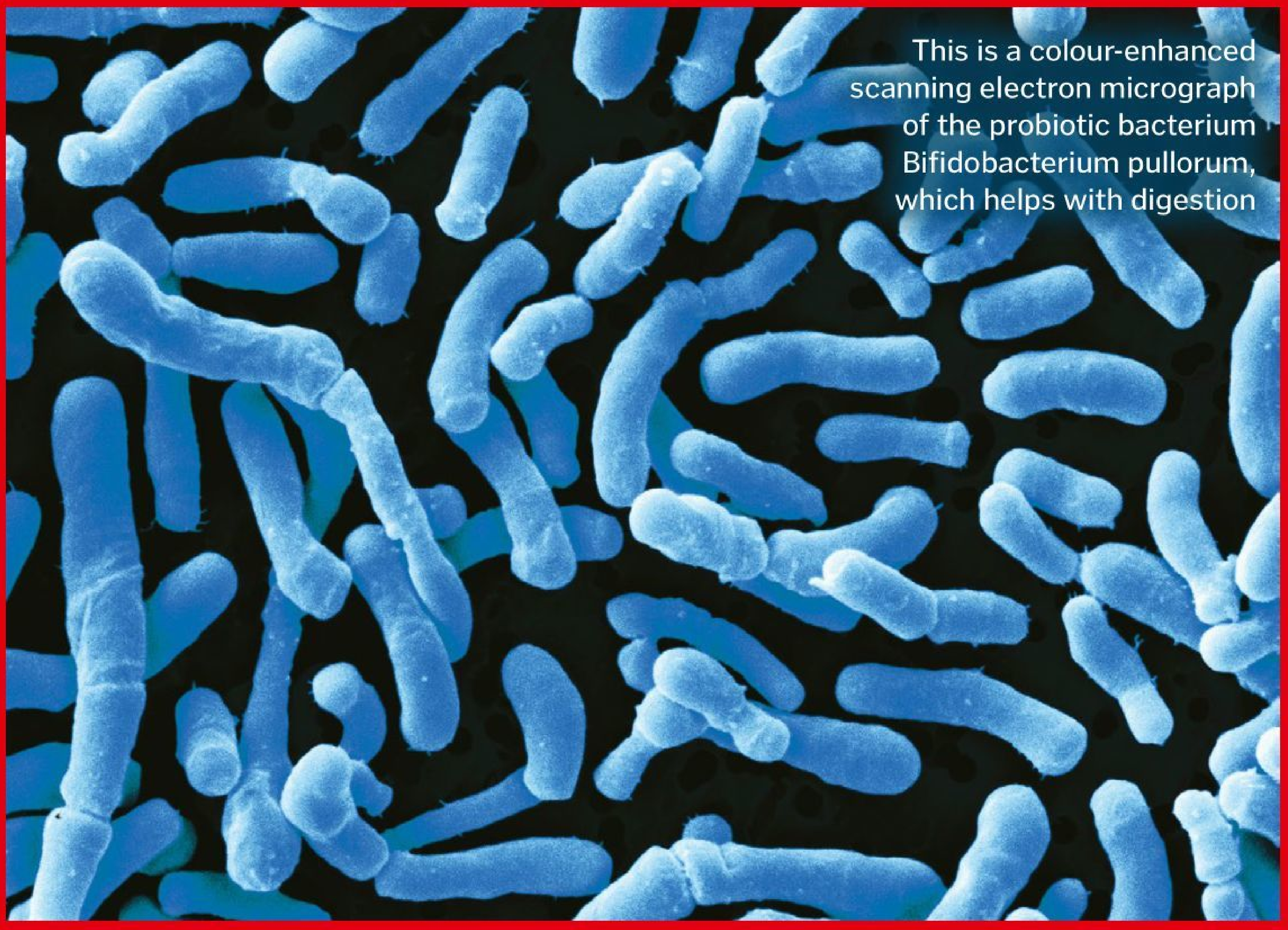
What are probiotic bacteria?

Not all bacteria are harmful, with some even bringing benefits to the human body

Contrary to almost a hundred years of bacteria being treated as something that must be eradicated – typically by using antibiotics – modern evidence has demonstrated that actually many bacteria are essential to humans and our daily functions.

The combination of these bacteria, which can be found throughout the body, is referred to as the human microbiome – encompassing all manner of microbes and their genetic elements. One notable example of these tiny organisms is Lactobacillus, a genus common in the human gastrointestinal tract known to produce a lactic acid environment that inhibits growth of some harmful bacteria. There are also various strains of Bifidobacterium, which aid the decomposition of carbohydrates and proteins.

Importantly, while research has confirmed many members of the microbiome do indeed aid bodily functions, additions included in probiotic foods – such as popular sweet yoghurt drinks – are yet to have their advertised benefits ratified by official bodies like the European Food Safety Authority (EFSA).



This is a colour-enhanced scanning electron micrograph of the probiotic bacterium Bifidobacterium pullorum, which helps with digestion

© Corbis; Thinkstock

DID YOU KNOW? *Surgery to remove the tonsils, known as a tonsillectomy, is carried out under general anaesthetic*

What are tonsils for?

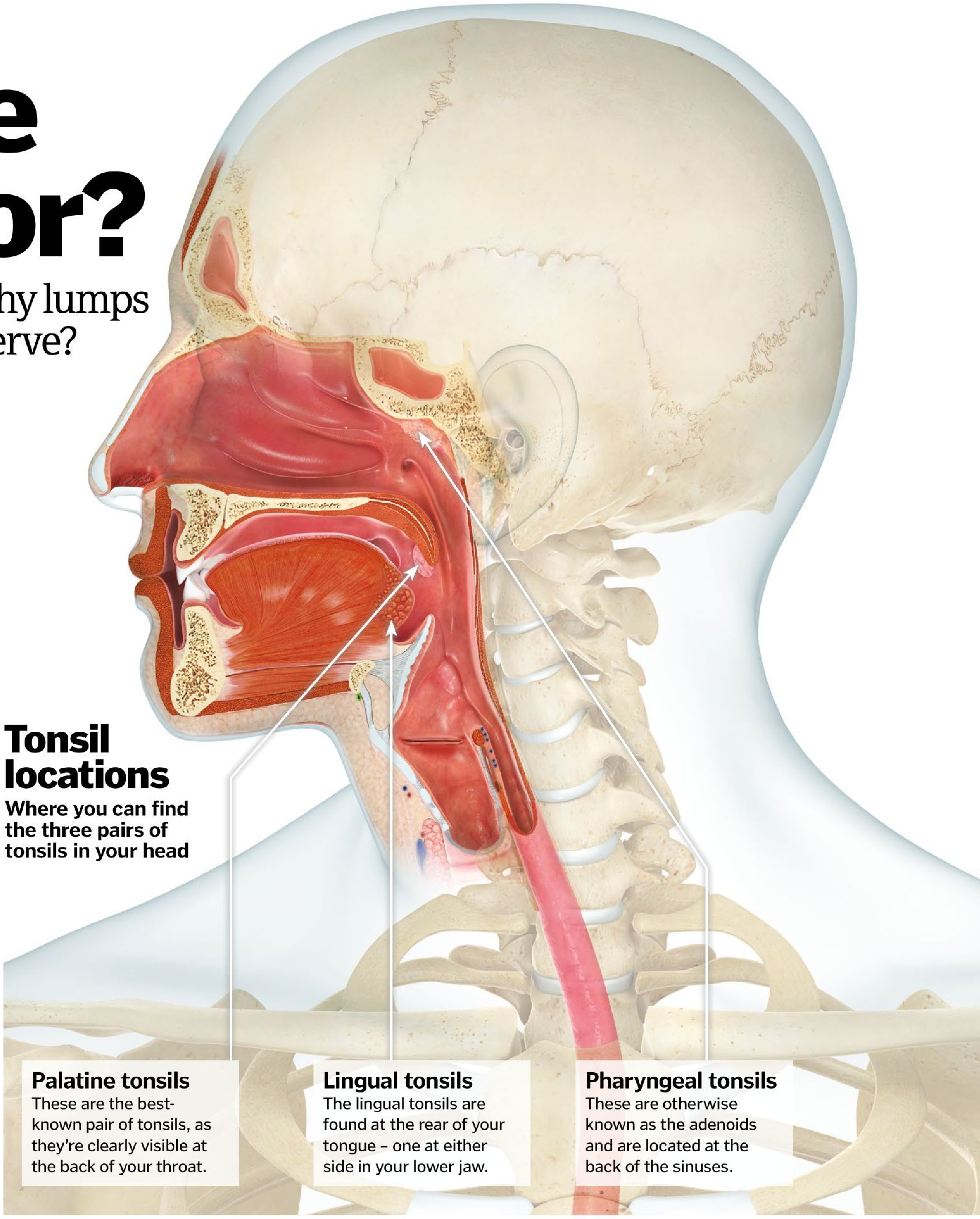
What purpose do these fleshy lumps in the back of our throats serve?

Tonsils are the small masses of flesh found in pairs at the back of the throats of many mammals. In humans the word is actually used to describe three sets of this spongy lymphatic tissue: the lingual tonsils, the pharyngeal tonsils and the more commonly recognised palatine tonsils.

The palatine tonsils are the oval bits that hang down from either side at the back of your throat – you can see them if you open your mouth wide in the mirror. Although the full purpose of the palatine tonsils isn't yet understood, because they produce antibodies and because of their prominent position in the throat, they're thought to be the first line of defence against potential infection in both the respiratory and digestive tracts.

The pharyngeal tonsils are also known as the adenoids. These are found tucked away in the nasal pharynx and serve a similar purpose to the palatine tonsils but shrink in adulthood.

Finally, the lingual tonsils are found at the back of the tongue towards the root where it attaches and, if you poke your tongue right out, you should be able to spot them. These are drained very efficiently by mucous glands and, as a result, they very rarely get infected.



Tonsil locations

Where you can find the three pairs of tonsils in your head

Palatine tonsils
These are the best-known pair of tonsils, as they're clearly visible at the back of your throat.

Lingual tonsils
The lingual tonsils are found at the rear of your tongue – one at either side in your lower jaw.

Pharyngeal tonsils
These are otherwise known as the adenoids and are located at the back of the sinuses.

Lots of bed rest, fluids and pain relief like paracetamol are all recommended for treating tonsillitis

Tonsillitis in focus

Tonsillitis is usually caused by certain bacteria (eg group A beta-haemolytic streptococci) and sometimes viral infections that result in a sore and swollen throat, a fever, white spots at the back of the throat and difficulty swallowing. Usually rest and a course of antibiotics will see it off, but occasionally the infection is very severe and can potentially cause serious problems, or reoccurs very frequently. In these cases a tonsillectomy may be considered – a surgical procedure where the tonsils are removed.

The adenoids are less commonly infected but, when they are, they become inflamed and swell to obstruct breathing through the nose and interfere with drainage from the sinuses, which can lead to further infections. In younger people, constant breathing through the mouth can stress the facial bones and cause deformities as they grow, which is why children will sometimes have their adenoid glands removed.

© Thinkstock; DK Images

Secrets of stem cells

Meet the miracle cells that might just revolutionise medicine

Stem cells are cells with the unique potential to become multiple different types of cell within the body.

Most of your cells are equipped to accomplish a specific job, whether carrying oxygen in your blood or transmitting messages to and from your brain. These specialists are known as differentiated cells.

Stem cells, on the other hand, have the flexibility to specialise into a variety of cell types. And unlike most differentiated cells, they can replicate many times, giving rise to both more stem cells and to specialised cells.

The most versatile stem cells are found in embryos just a week old. Embryonic stem cells (ESCs) transform the embryo from a tiny ball of unspecialised cells into a baby, generating all of the 250-odd cell types in the human body. A biological blank slate, their vast – and highly coveted – potential is known as pluripotency.

After birth, stem cells continue to play a vital role as your body's maintenance and repair kit, taking up residence in tissues such as the brain, bone marrow, liver, heart muscles, skin and gut. Adult stem cells are less flexible than their embryonic counterparts, generating a more limited range of cell types. The haematopoietic stem cells found in bone marrow, for example, are dedicated solely to producing blood cells.

When it comes to researching stem cells and the therapies that rely on them, getting hold of these cells is a major obstacle. ESCs are taken from donated embryos from IVF procedures, but this stirs up thorny ethical issues.

Although challenging to work with, adult stem cells dodge some of these ethical quandaries, leading many to store their offspring's stem cell-rich umbilical cord blood. Furthermore, tissues that have been generated from a patient's own stem cells don't risk rejection by their immune system.

Coloured SEM of a human embryo at the 16-cell stage on the tip of a pin. Embryonic stem cells are the most flexible, able to form into all three primary germ layers: ectoderm, endoderm and mesoderm

Stem cell milestones

It's still early days, but stem cells show every intention of keeping their promises. Pioneering surgeon Paolo Macchiarini, based at Sweden's Karolinska Institute, carried out the first organ transplant using a windpipe grown from adult stem cells in 2008. Since then, he has built new tracheas for several patients using a synthetic scaffold.

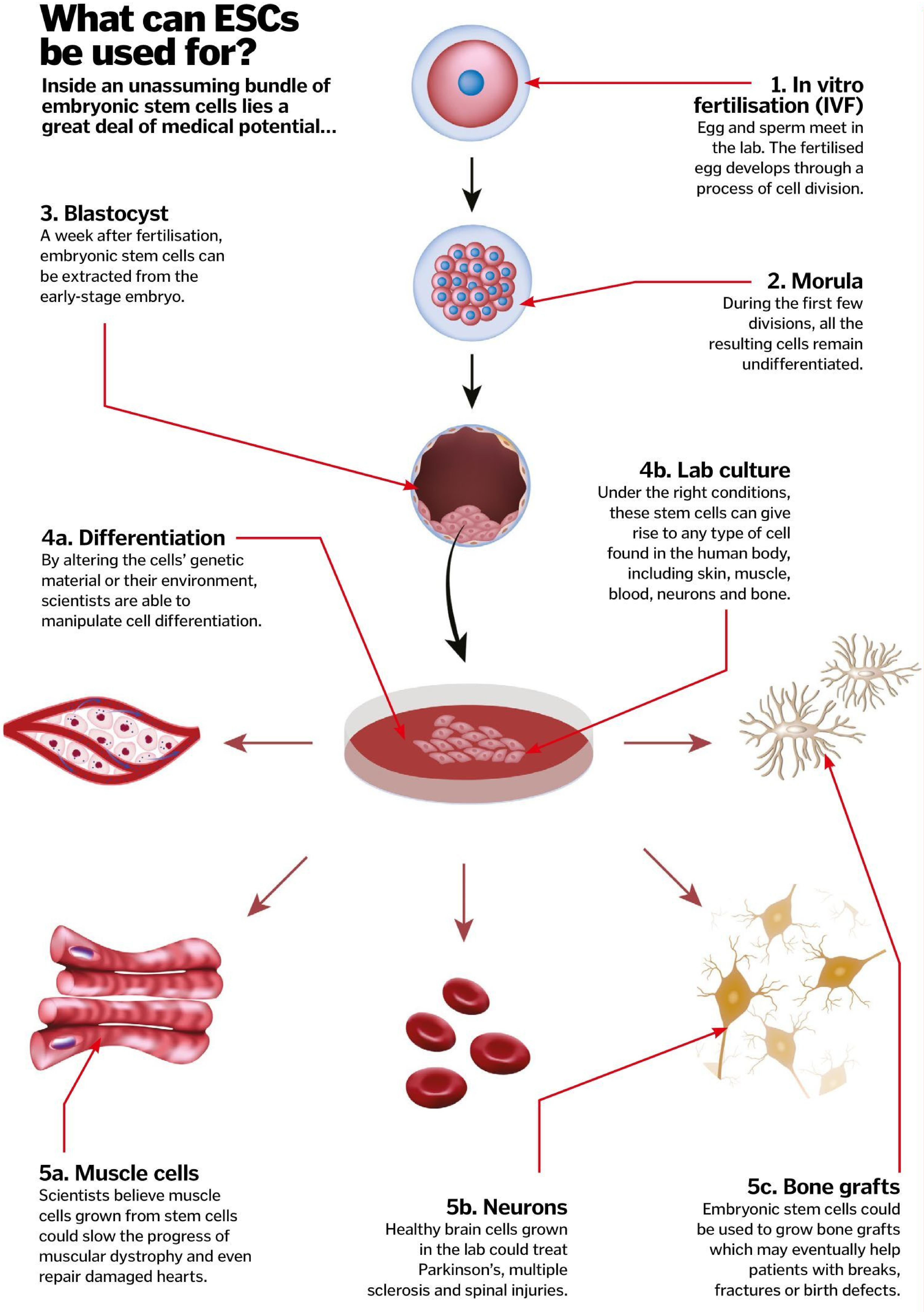
Research into therapy for type-I diabetes has also made impressive progress. Sufferers' lymphocytes (a key part of the body's immune system) attack the pancreas, preventing the production of insulin. Exposing them to healthy lymphocytes grown from cord blood stem cells, however, appears to 're-educate' them, limiting their harmful behaviour.

Induced pluripotent stem cells (otherwise known as iPSCs) obtained by manipulating mature specialised cells could well resolve the ethical controversy which currently restricts embryonic stem cell research.

DID YOU KNOW? *Salamanders' impressive stem cells mean they can regenerate their legs, heart, brain, spine and more*

What can ESCs be used for?

Inside an unassuming bundle of embryonic stem cells lies a great deal of medical potential…



1. In vitro fertilisation (IVF)
Egg and sperm meet in the lab. The fertilised egg develops through a process of cell division.

2. Morula
During the first few divisions, all the resulting cells remain undifferentiated.

3. Blastocyst
A week after fertilisation, embryonic stem cells can be extracted from the early-stage embryo.

4a. Differentiation
By altering the cells' genetic material or their environment, scientists are able to manipulate cell differentiation.

4b. Lab culture
Under the right conditions, these stem cells can give rise to any type of cell found in the human body, including skin, muscle, blood, neurons and bone.

5a. Muscle cells
Scientists believe muscle cells grown from stem cells could slow the progress of muscular dystrophy and even repair damaged hearts.

5b. Neurons
Healthy brain cells grown in the lab could treat Parkinson's, multiple sclerosis and spinal injuries.

5c. Bone grafts
Embryonic stem cells could be used to grow bone grafts which may eventually help patients with breaks, fractures or birth defects.

Stem cells to the rescue

Allowing researchers to watch cell specialisation unfold before their eyes, stem cells deliver unprecedented insight into many diseases and birth defects. Stem cells share many traits with cancer cells and could therefore reveal some of their secrets; some speculate that cancer may even be driven by out-of-control stem cells.

Many future treatments aim to harness stem cells' regenerative properties. Healthy cell and tissue transplants could patch up patients with a variety of different complaints, from diabetes to Parkinson's. Trials suggest, for instance, that injecting failing hearts with stem cells could grant them a new lease of life.

Tissues made from stem cells may also enable new medications to be tested on human cells in the early stages of drug development. One day, entire organs might be grown in the lab from patients' own stem cells, dramatically cutting waiting lists for organ donors. In the meantime, scientists need plenty more time to research the finer details of controlling cell differentiation.

Professor of Stem Cell Science

Newcastle Uni's Majlinda Lako discusses super cells

What's left to learn about stem cells?
We know that stem cells are present at all stages of our life. Stem cells found in early embryos have the potential to become different types of cell, while adult stem cells are more specific.

The questions we are trying to answer are: can we identify all stem cells? Can we grow them in large numbers in the lab? Can we make them give rise to any cells we wish? Can we use stem cells to treat cancer, ageing and degenerative diseases?

Does every multicellular organism have stem cells?
Yes. In mammals, there are two main types of stem cells: embryonic, which are generated from early embryos, and adult, which are found in various tissues and contribute to the repair and replenishment of our tissues. For a long time it was thought that once the stem cells changed to form the various cells that make up our organs, it was impossible to make them revert back to the initial stem cell state. However, the Nobel prize winner Shinya Yamanaka reported in 2006 that adult cells can be turned back to the embryonic stage by simple genetic manipulation.

Who first discovered stem cells?
The concept of stem cells was first mentioned by Valentin Haecker and Theodor Boveri in the 19th century. In parallel, Artur Pappenheim, Alexander Maksimov, Ernst Neumann and others used it to describe a proposed origin of the blood system. As the field progressed, the term 'stem cell' has been used to describe the capacity of stem cells for self-renewal as well as the ability to give rise to all cell types that make up our bodies.

Do stem cells have to be prompted in some way to repair the body?
Adult stem cells need prompting if a quick repair is needed, and we can achieve this in the lab. Stem cell prompting in the body is a bit more tricky, but can occur in response to specific stress or injuries.

© SPL

Colour blindness

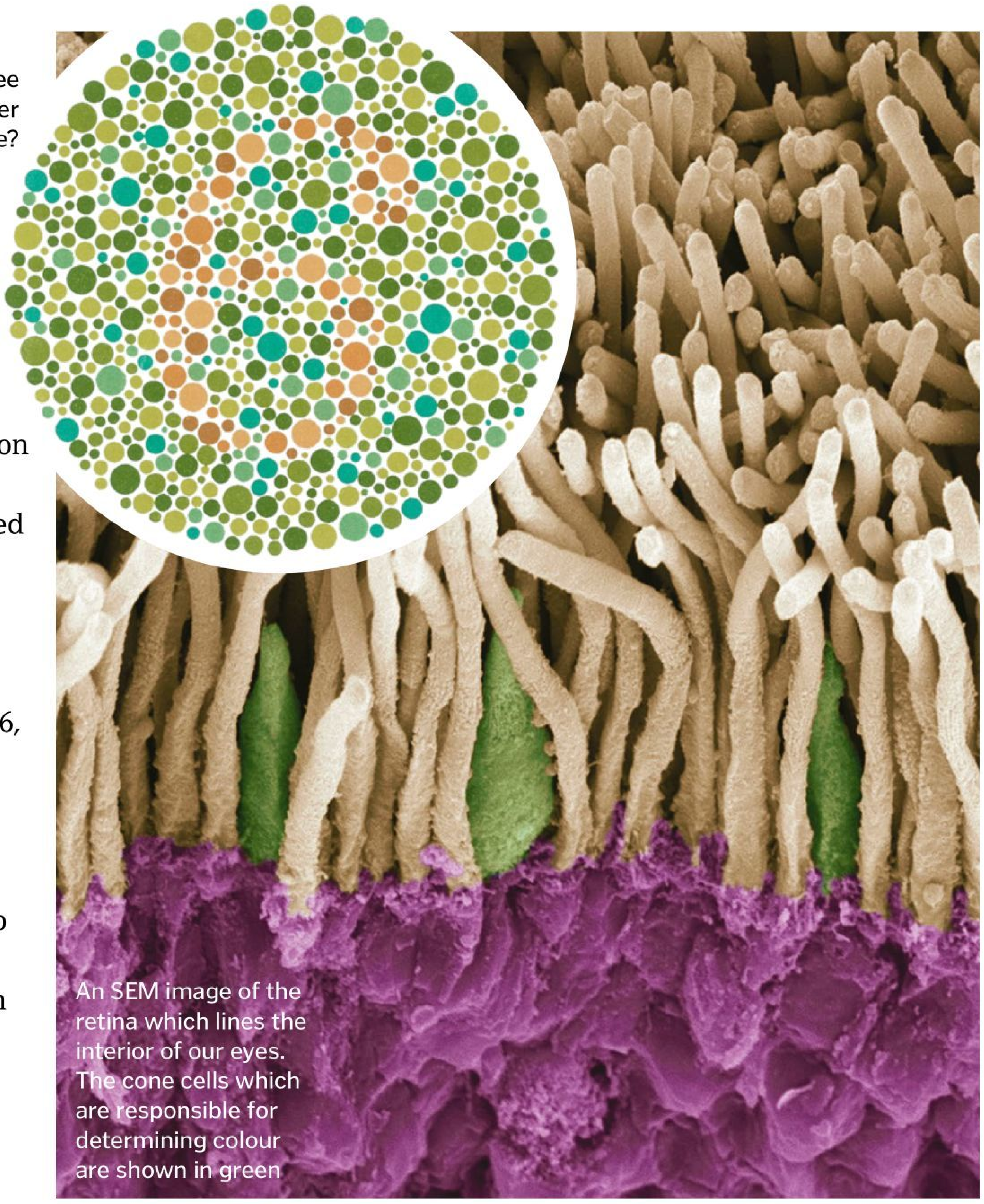
Why do some people have trouble distinguishing between colours?

The human eye has three types of light-detecting cone cells, which contain pigments sensitive to different wavelengths of light: long (red), medium (green) and short (blue). The differences in the overlapping signals from all three are used by the brain to perceive colour.

Colour blindness occurs when one or more of the cone cells do not work properly. The most common form of colour blindness (which accounts for over 95 per cent of cases) affects perception of light at longer wavelengths, leading to difficulty distinguishing between red and green. Yellow-blue colour blindness occurs occasionally, and a few people can't see any colour at all.

Colour blindness is more common in men than in women. This is because many of the genes involved in colour vision are found on the X chromosome. For a male (46, XY) a defect on his only X chromosome is sufficient to cause colour blindness, whereas for a female (46, XX) both X chromosomes must be defective – this latter scenario occurs much less frequently.

Research has shown that individuals unable to use colour to differentiate between objects develop superior visual skills with regard to identifying texture and shape. This enables them to see 'through' colour camouflage in a way that people with normal three-colour vision cannot.



Can you see the number hidden here?

An SEM image of the retina which lines the interior of our eyes. The cone cells which are responsible for determining colour are shown in green

What causes stomach ulcers?

Originally thought to be the result of stress, we now know that bacteria are the culprits…

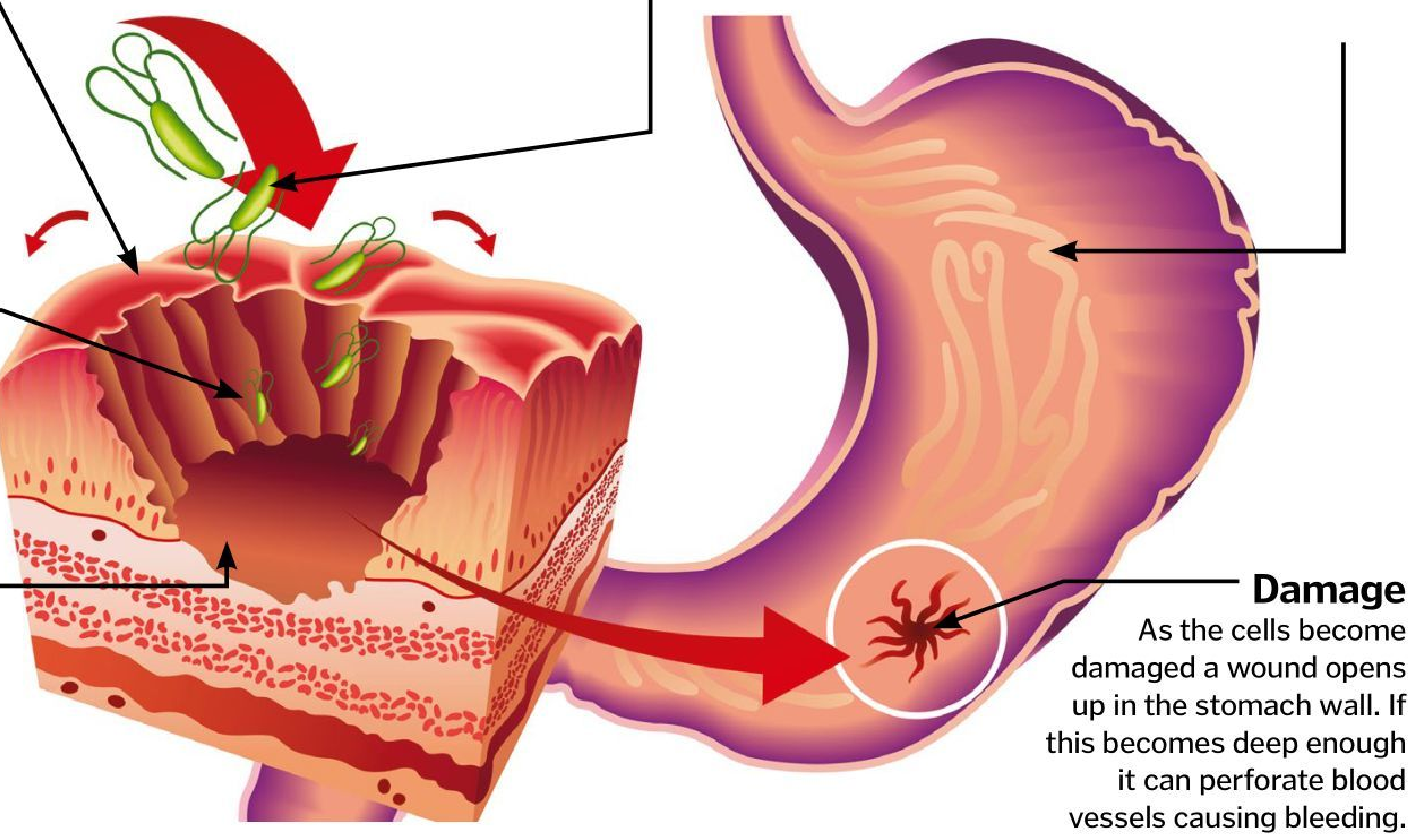
Normally a thick layer of alkaline mucus effectively protects the cells lining the stomach from the low pH of stomach acid. If this mucus becomes disrupted, however, acid comes into contact with the organ's lining, damaging the cells and resulting in an ulcer.

Around 60 per cent of stomach ulcers are caused by inflammation due to chronic infection by the bacterium Helicobacter pylori. Bacterial by-products cause damage to the cells lining the stomach, causing a breakdown of the top layers of tissue.

Non-steroidal anti-inflammatory drugs (NSAIDs), like ibuprofen and aspirin, also cause stomach ulcers in large doses. They disrupt the enzymes responsible for mucus production, diminishing the protective barrier.

An ulcer in the making

Once bacteria breach the stomach lining, it can no longer protect itself from its acidic contents…



Neutralising stomach acid
H pylori break down urea to make ammonia. This is used to produce bicarbonate to neutralise dangerous stomach acid.

Ammonia
The ammonia made by the bacteria as a defence against acid damages the cells lining the stomach, causing inflammation.

Enzymes
H pylori produce proteases and phospholipases – enzymes that damage the proteins and cell membranes of the stomach cells.

Helicobacter pylori
Bacteria burrow through the mucus in the stomach to escape damage by acid. They stick strongly to the cells of the interior lining.

Gastrin
The inflammatory response increases production of the hormone gastrin. This in turn stimulates the formation of more stomach acid.

Damage
As the cells become damaged a wound opens up in the stomach wall. If this becomes deep enough it can perforate blood vessels causing bleeding.

© Corbis

DID YOU KNOW? *The chickenpox vaccine was developed by Japanese physician Michiaki Takahashi*

Understanding chickenpox

Discover the biology behind the infamous childhood ailment and why it never really goes away…

Chickenpox is a strain of the Varicella zoster virus, which many of us have experienced during our youth. Most prominent in children under ten, the virus is contracted through coughing and sneezing or transferred on shared objects, which makes schools a prime location.

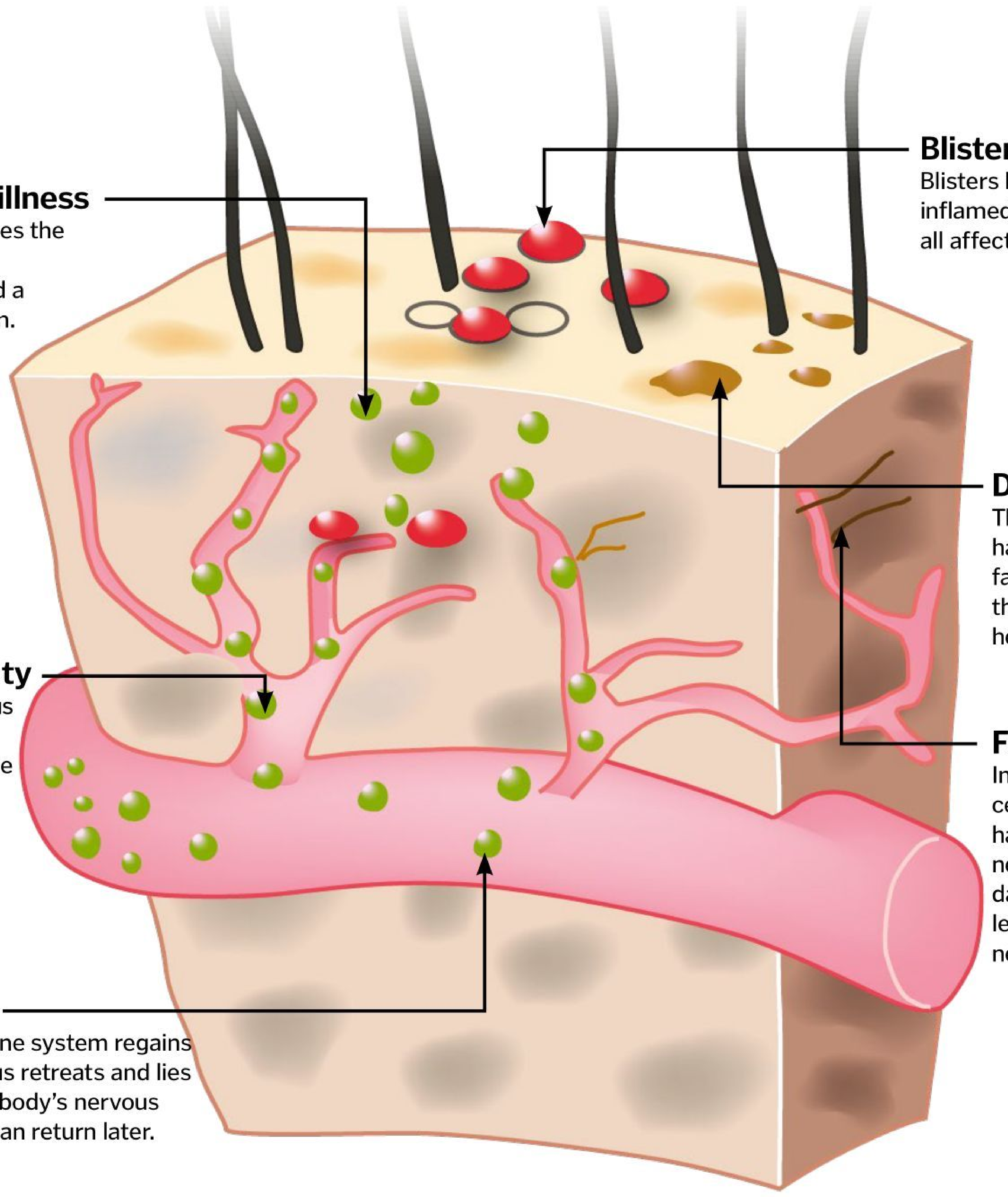
The most famous symptom is the appearance of small itchy red spots, which vary in size from 10-20 millimetres (0.4-0.8 inches) across. The extent can vary but in most cases they cover the face, arms, legs, stomach and back. These develop into fluid-filled blisters and are often accompanied by a fever. The blisters burst, scab over and fall off within a few days, but new waves of spots can emerge to replace them; it usually takes one to two weeks for the body to regain control. Chickenpox is rarely serious but it is important not to interfere with the scabs as infection can make it more severe.

A vaccine is only offered in extreme circumstances when an individual may have a weak immune system or be particularly vulnerable to the disease.

After the outbreak, chickenpox doesn't disappear entirely. The disease lies in a dormant state within the body as your immune system keeps it under wraps. The infection can break out again later and reappear as shingles. A rash builds up on a certain point of the body and the symptoms return, most commonly in people over 50. On average, three in every 1,000 people contract shingles in the UK each year.

When chickenpox strikes back…

Get under the skin to see how shingles can catch the body unawares



Start of the illness
The virus infiltrates the skin and causes inflammation and a burning sensation.

Blisters emerge
Blisters become visible and inflamed rashes appear on all affected areas.

Don't scratch!
The blisters then harden into scabs and fall off. Scratching at the spots makes the healing process slower.

Low immunity
The Varicella virus becomes active when the immune system is weak, overcoming the body's natural defences.

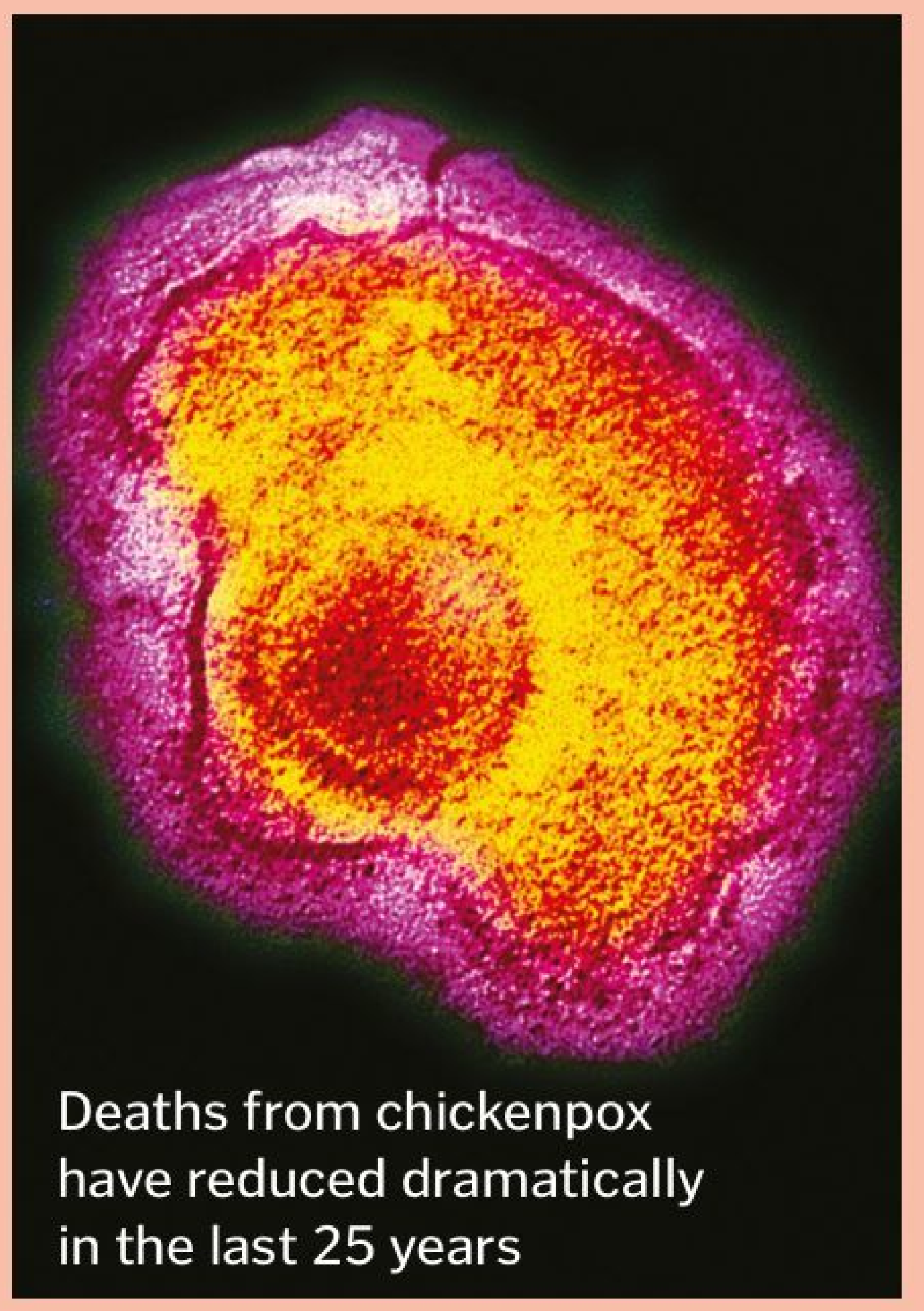
Future effects
In around 10-20 per cent of people who have shingles, the nerve fibres become damaged which can lead to postherpetic neuralgia (nerve pain).

Dormancy
Once the immune system regains control, the virus retreats and lies dormant in the body's nervous system, but it can return later.

Grown-up chickenpox

90 per cent of adults are immune if they've had the disease as a child but it still affects adults and teenagers. If you develop chickenpox at a later age, all the symptoms are more severe, with more chronic pain, headaches and sore throats; therefore, there is greater need for treatment, such as pain relief and soothing creams.

The disease tends to affect adults more dramatically as it can now mutate into a variety of other strains, such as shingles or, in extreme cases, lead to encephalitis, postherpetic neuralgia or pneumonia. However, the chances of this happening are only around ten per cent.



Deaths from chickenpox have reduced dramatically in the last 25 years

© Alamy; Thinkstock

The war against superbugs

Learn how bacteria will hide, change, lie and cheat to evade antibiotics and secure their survival

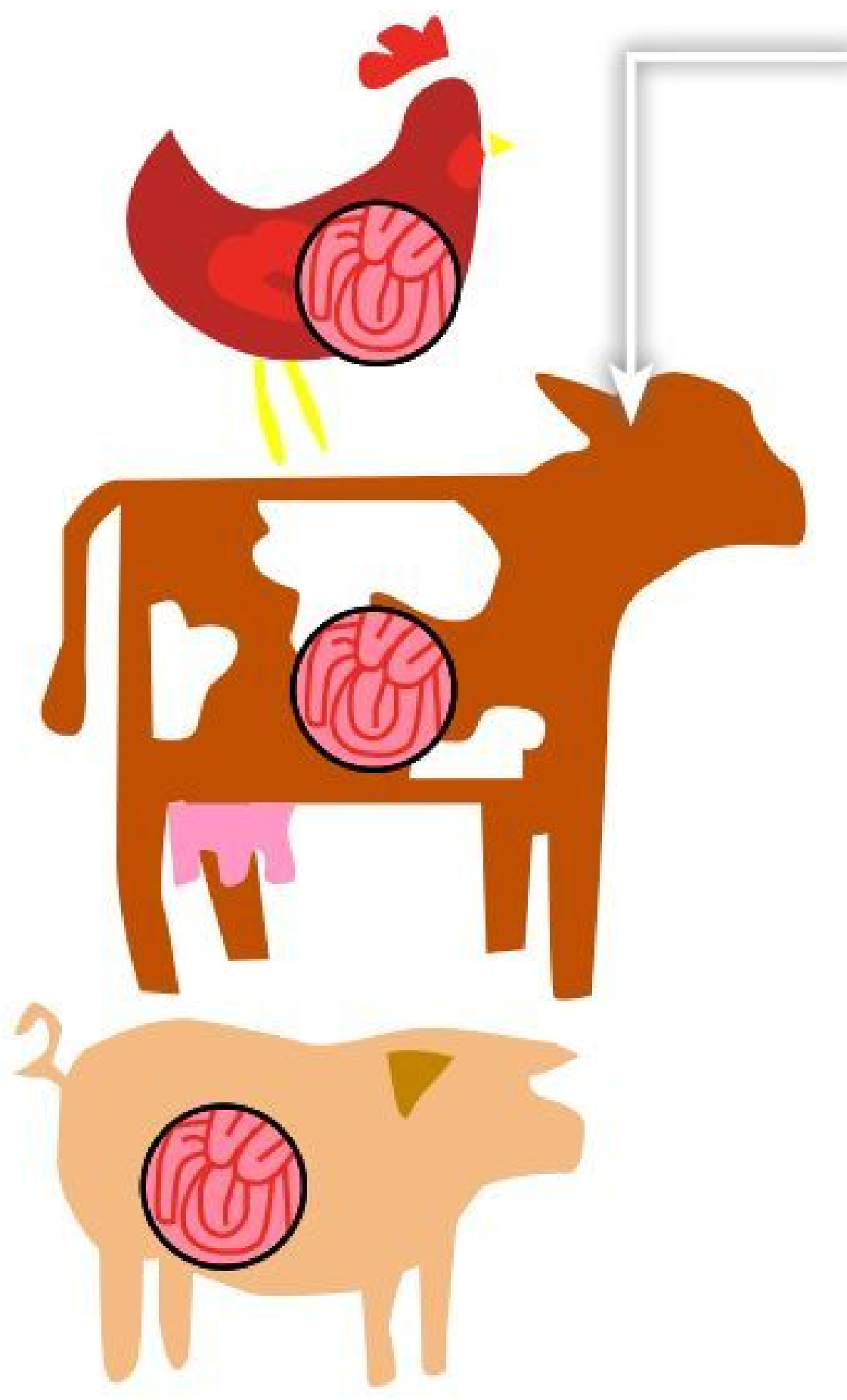
Bacteria are vital to our survival. They help us digest food, keep our skin clean from more harmful organisms and help develop our advanced immunity while we're young. However, they can also cause disease, which ranges from simple eye infections to life-threating illnesses.

Antibiotics were discovered in 1928 and almost overnight they changed what were once fatal diseases into trivial infections. But despite effective medication, bacteria are smart and know how to fight back. They can change their shape, hide in plain sight and alter their surface appearance. After an attack from antibiotics, the few bacteria left over are the strongest of the bunch and are resistant to the current crop of antibiotics; this is true survival of the fittest. The lasting bacteria then multiply, become stronger and are able to survive attacks from other antibiotics. This is known as 'multidrug resistance' and has led to certain bacteria being ominously called 'superbugs.'

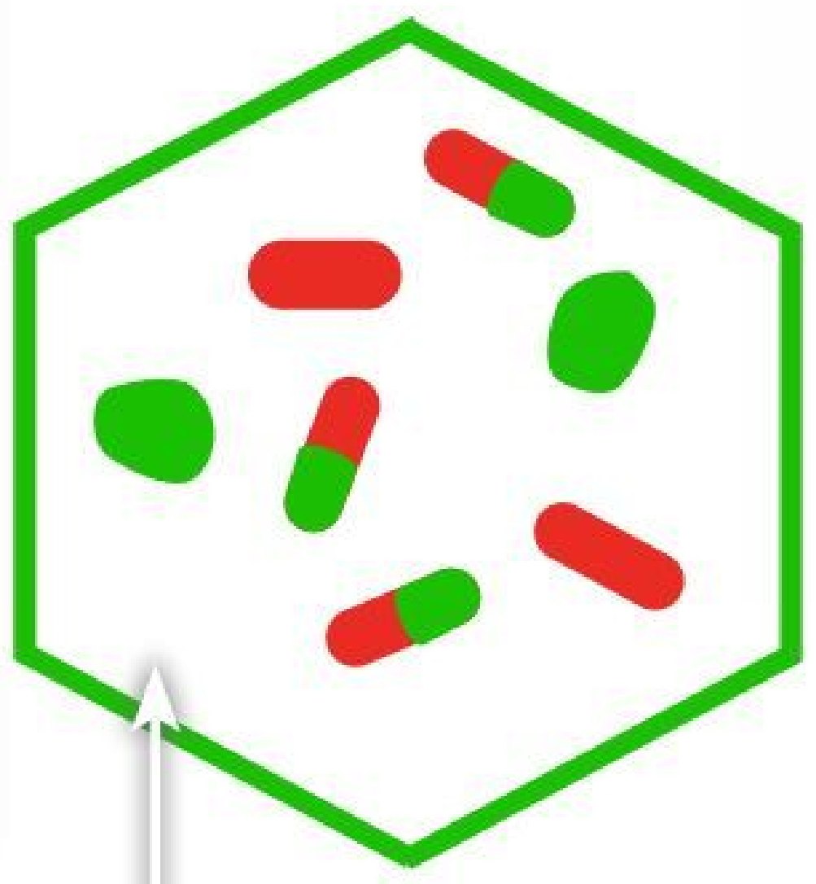
Over the last 30 years, it's been stated that too many antibiotics have been prescribed, which has contributed to this resistance. This is why doctors no longer give antibiotics for simple colds; they have no effect on viruses but contribute to antibiotic resistance.

The revenge of the superbug

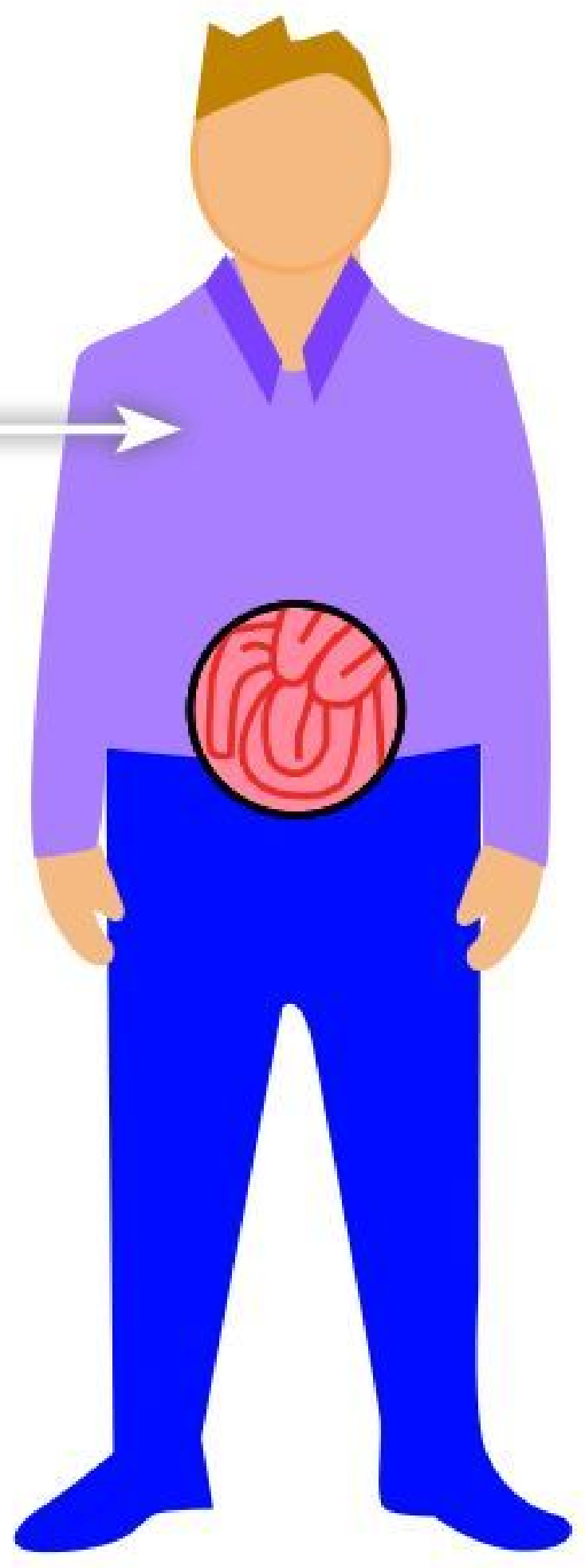
How the toughest bacteria are taking over



Bottom of the food chain
Modern farming techniques mean animals are given antibiotics to keep them healthy. They subsequently develop resistant bacteria in their guts.



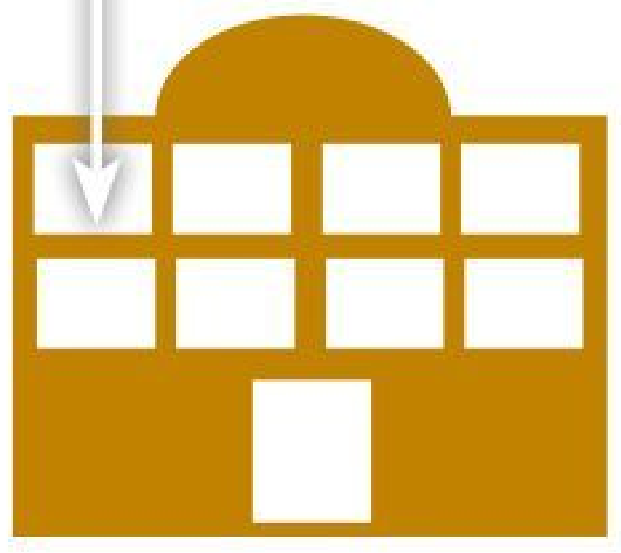
Realm of the superbug
The remaining bacteria are now resistant to even the strongest antibiotics and are called superbugs. They spread as patients move and on healthcare staff who go between patients.



Resistance in humans
Antibiotics given for simple illnesses lead to resistance in healthy people.

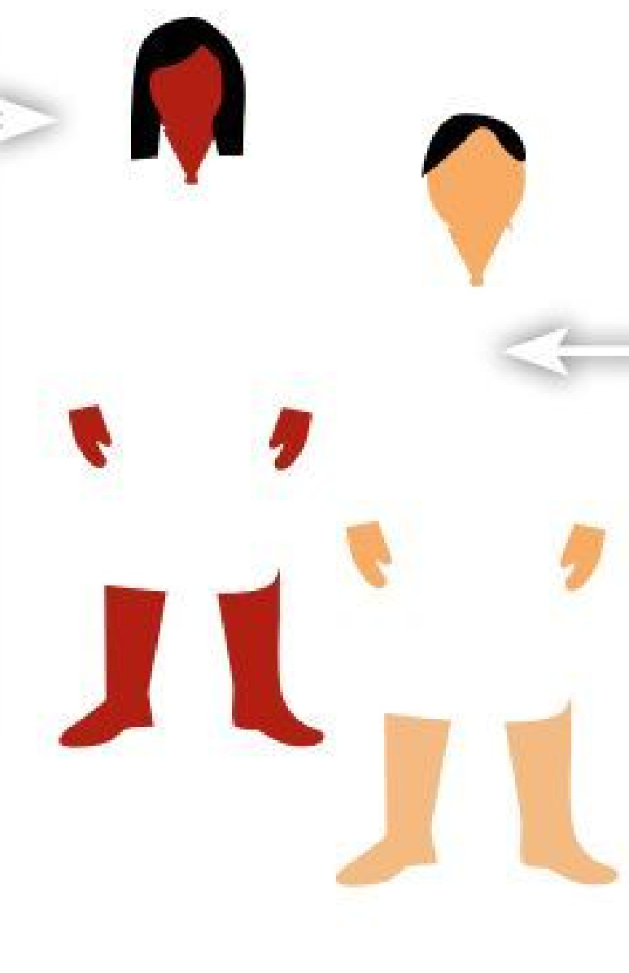
Entering our food chain
The resistant bacteria in food and vegetables can remain in the human gut once we've eaten them.

Community resistance
Community resistance gradually develops, helping the toughest bacteria to establish and spread.



Entering hospitals
As patients enter and leave hospitals, these tough bugs start growing in wards and nursing homes.

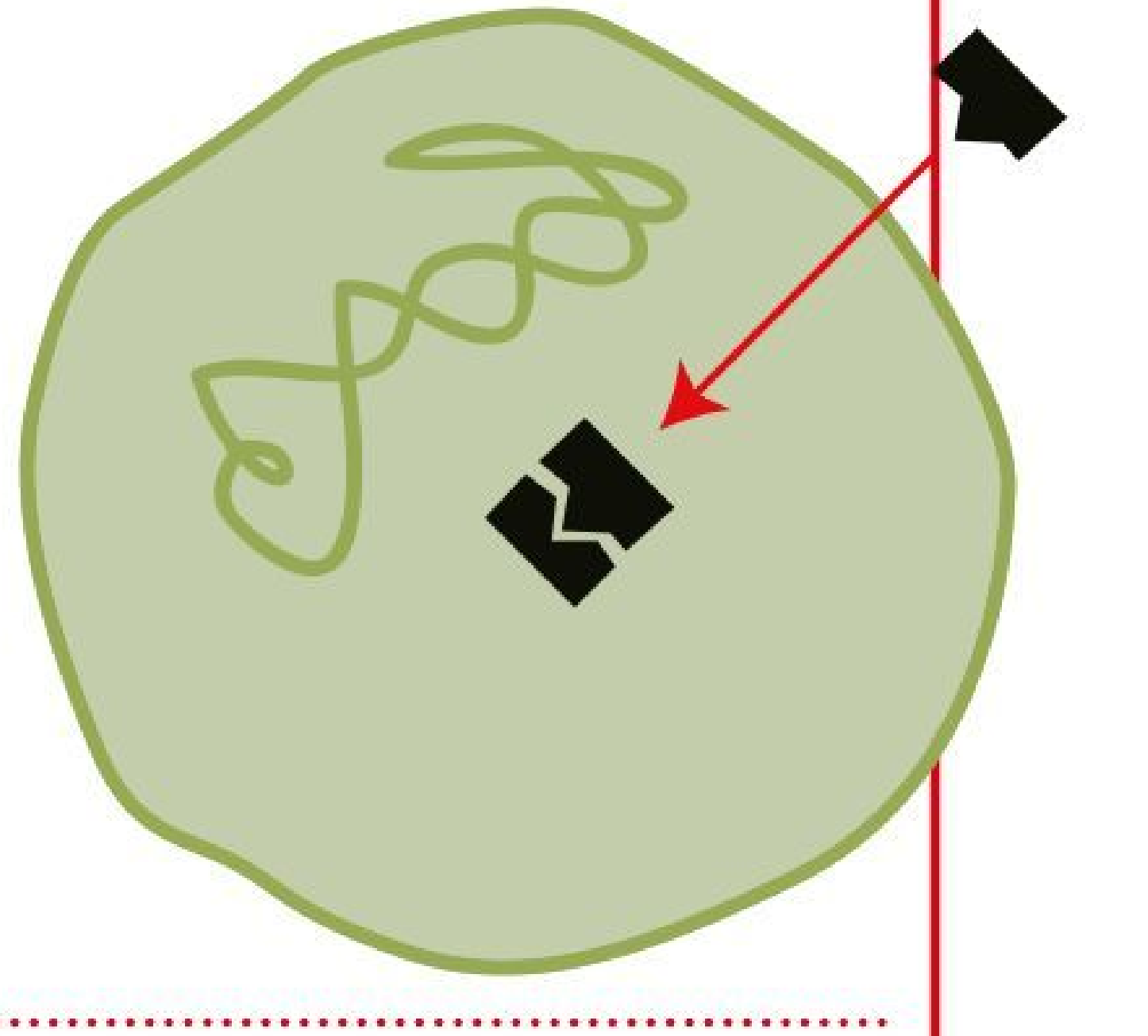
Crop circles
Fertiliser used on crops contains animal matter, which also contains the resistant bacteria, increasing their spread.



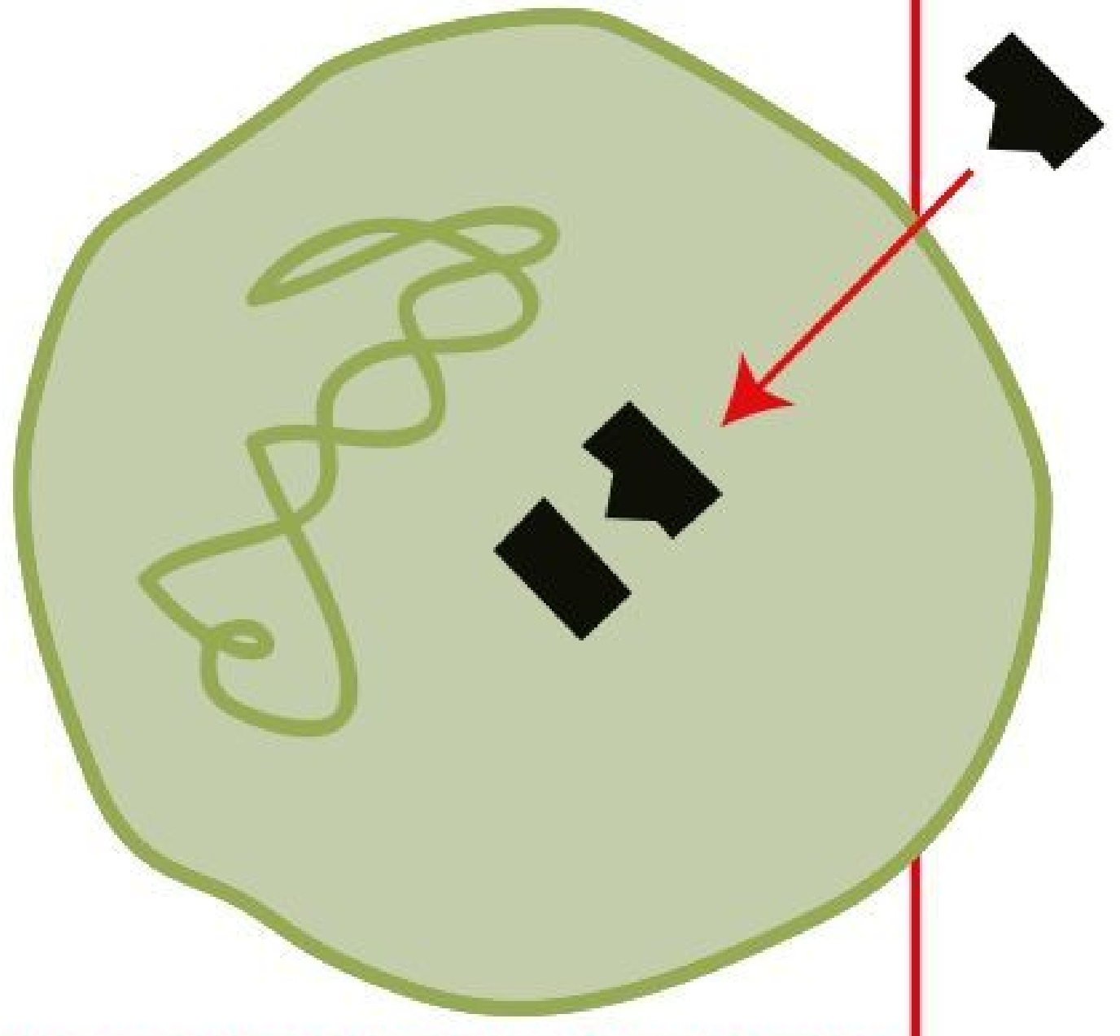
Weak targets
They cause infections, secondary to the main reason the patient is in hospital. Doctors treat these, but some bacteria still remain.

Future strategies
Doctors only prescribe antibiotics for as short a time as possible. New and smarter antibiotics tackle even the toughest of resistance.

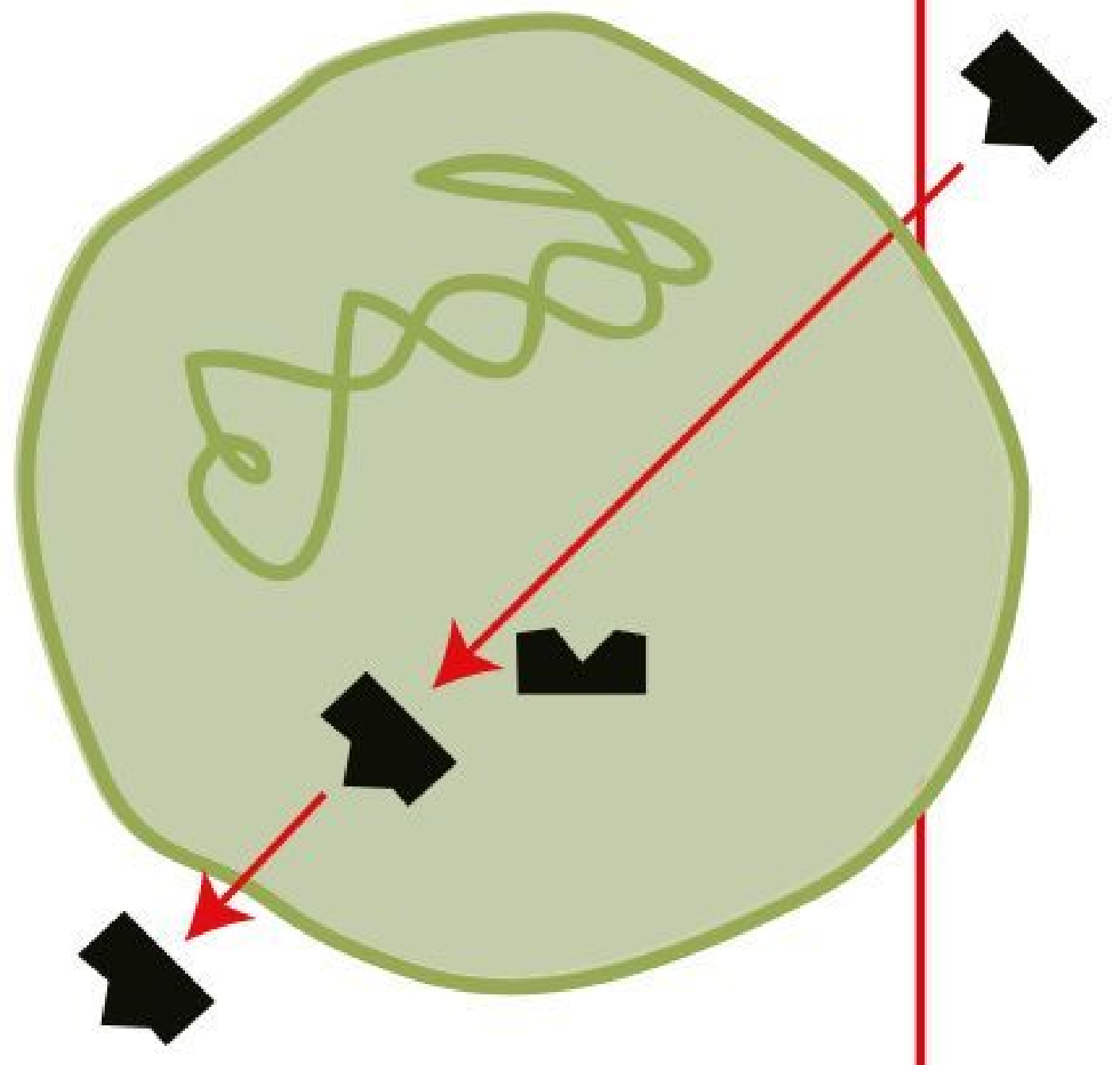
How antibiotic resistance develops



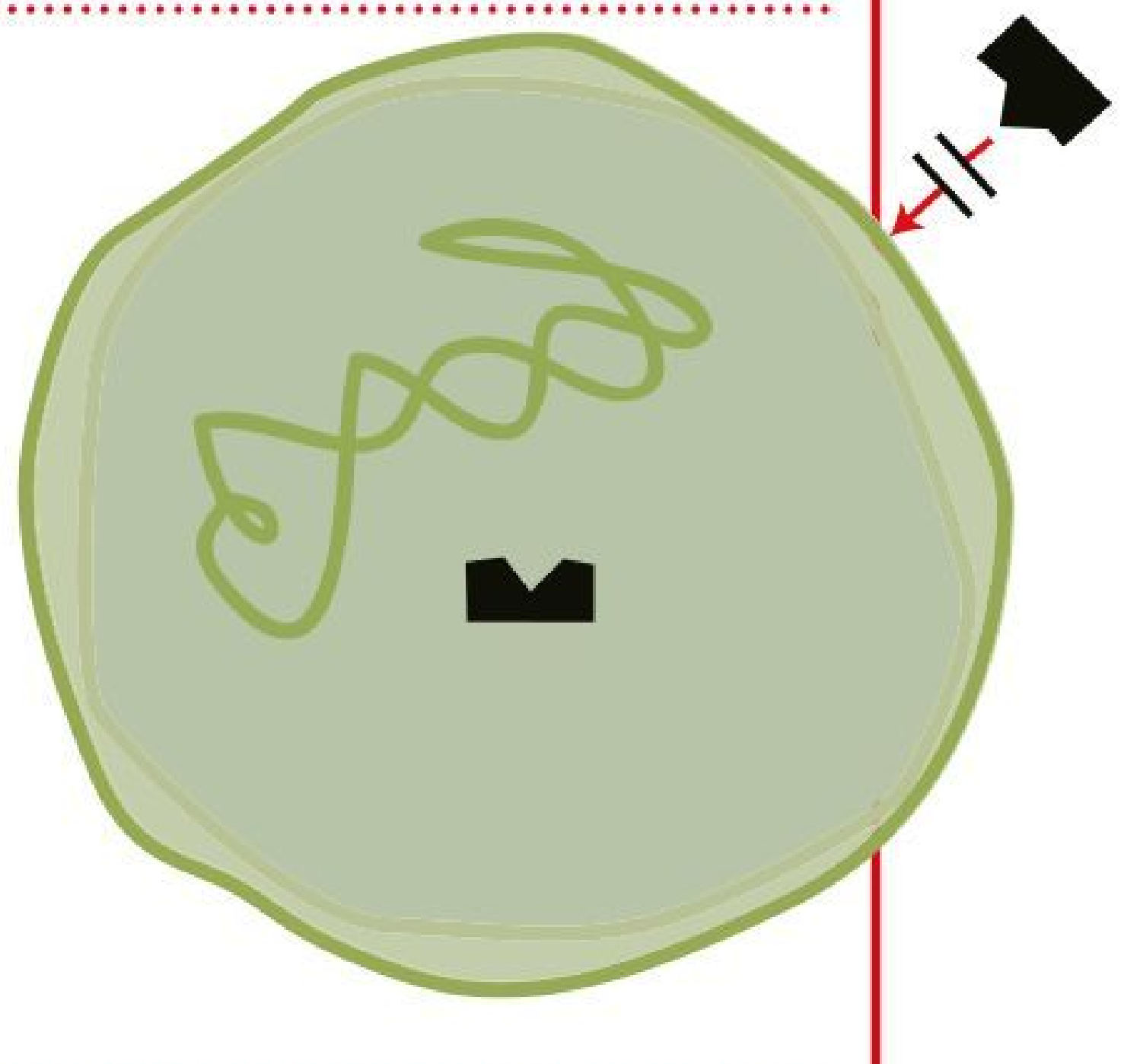
Normal function
Antibiotics target bacterial cells, by changing the signals of their outer wall, their membrane shape, impairing DNA function in the cell or by blocking protein synthesis.



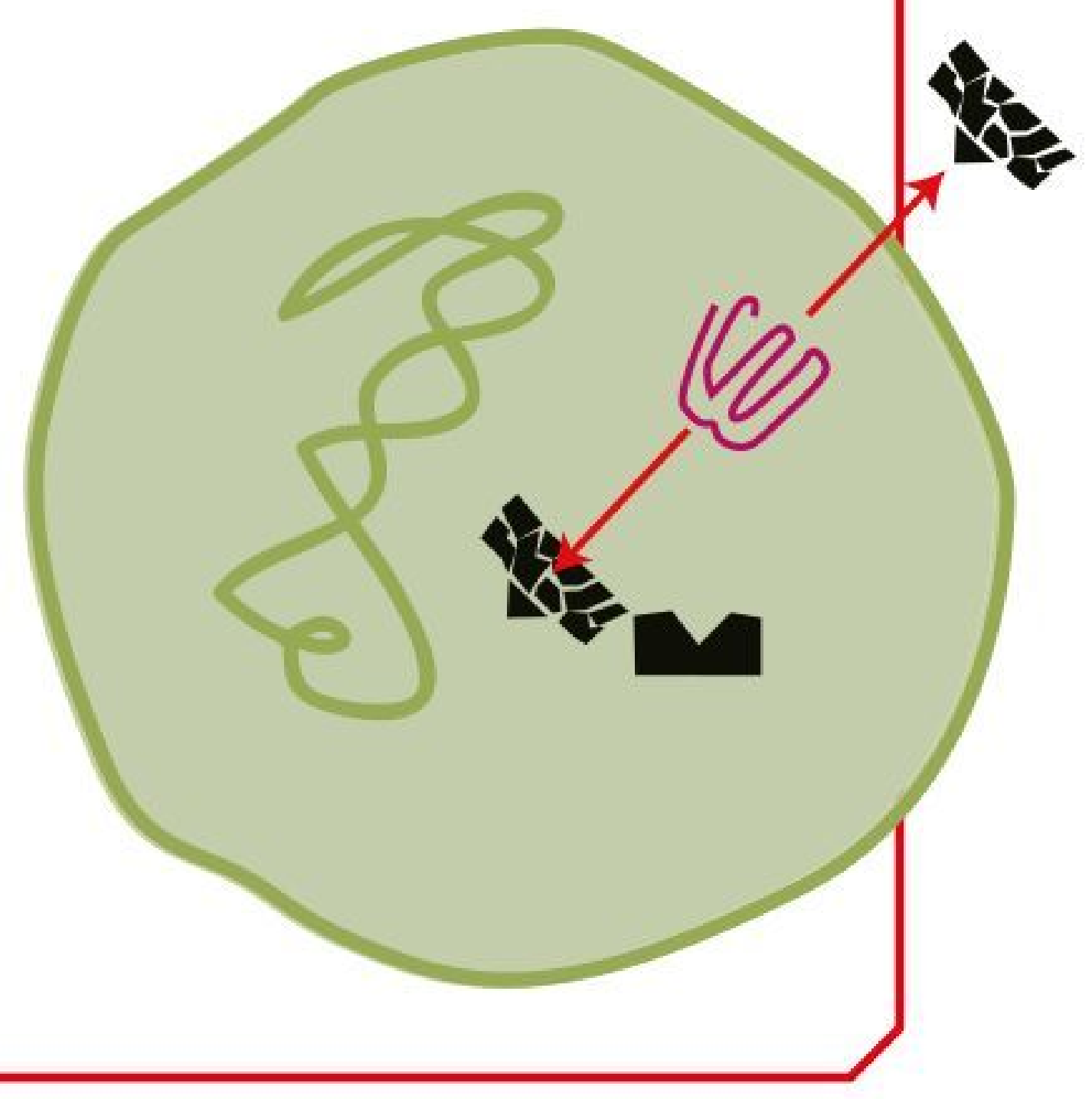
Changing the landing zone
Bacteria can change the shape and structure of the molecules that antibiotics target, meaning they can't recognise them and rendering them useless.



One in, one out
Antibiotics enter bacterial cells via special pumps. The bacteria can develop more exit than entry pumps, meaning the antibiotic is exited faster than it can enter.



Entry policy
Bacteria can stop antibiotics entering: they can change the shape of entry pumps and reduce the size of pores in their surface, meaning the antibiotics are too large to enter.



Inactivation
The strongest bacteria develop special enzymes, which can destroy the key parts of an antibiotic before they have a chance to take effect.

DID YOU KNOW? *Around one in six of the UK population is believed to have some form of hearing loss*

Curing deafness

We're getting ever closer to restoring the gift of hearing

There are more than 250 million people in the world who suffer from hearing loss or deafness, but it seems there is hope for them now.

Humans are able to hear things thanks to thousands of tiny hairs just inside their ears that vibrate when sound waves hit them. Sensory hearing loss occurs when they die or become damaged, meaning that they are no longer able to perform that action. This usually happens when the ear has been subjected to loud noises or the hair no longer regrows, often due to old age or natural degeneration.

Fortunately, scientists have been working hard to reverse that process. A study by British scientists has found that there is a protein contained in the body called Notch that stops new ear hair cells growing from stem cells. They have developed a drug that blocks this protein, meaning the body can regrow those crucial ear hairs.

A second experiment carried out by the University of Kansas injected a harmless virus into the ears of patients, which had a gene called Atoh1 in it, which stimulated the growth of the sensory hairs.

While we are still an awfully long way from being able to cure deafness from birth, these developments mean that people who have steadily lost their hearing could soon have it back, as loud and clear as ever.

Help for hearing

While the prospect of regrowing sensory hair cells and curing deafness is really exciting, there have been ways of helping people hear for a long while now. Ear trumpets were used in the 17th century as a popular way of helping people hear as they provided a much wider area for the sound waves to get trapped in.

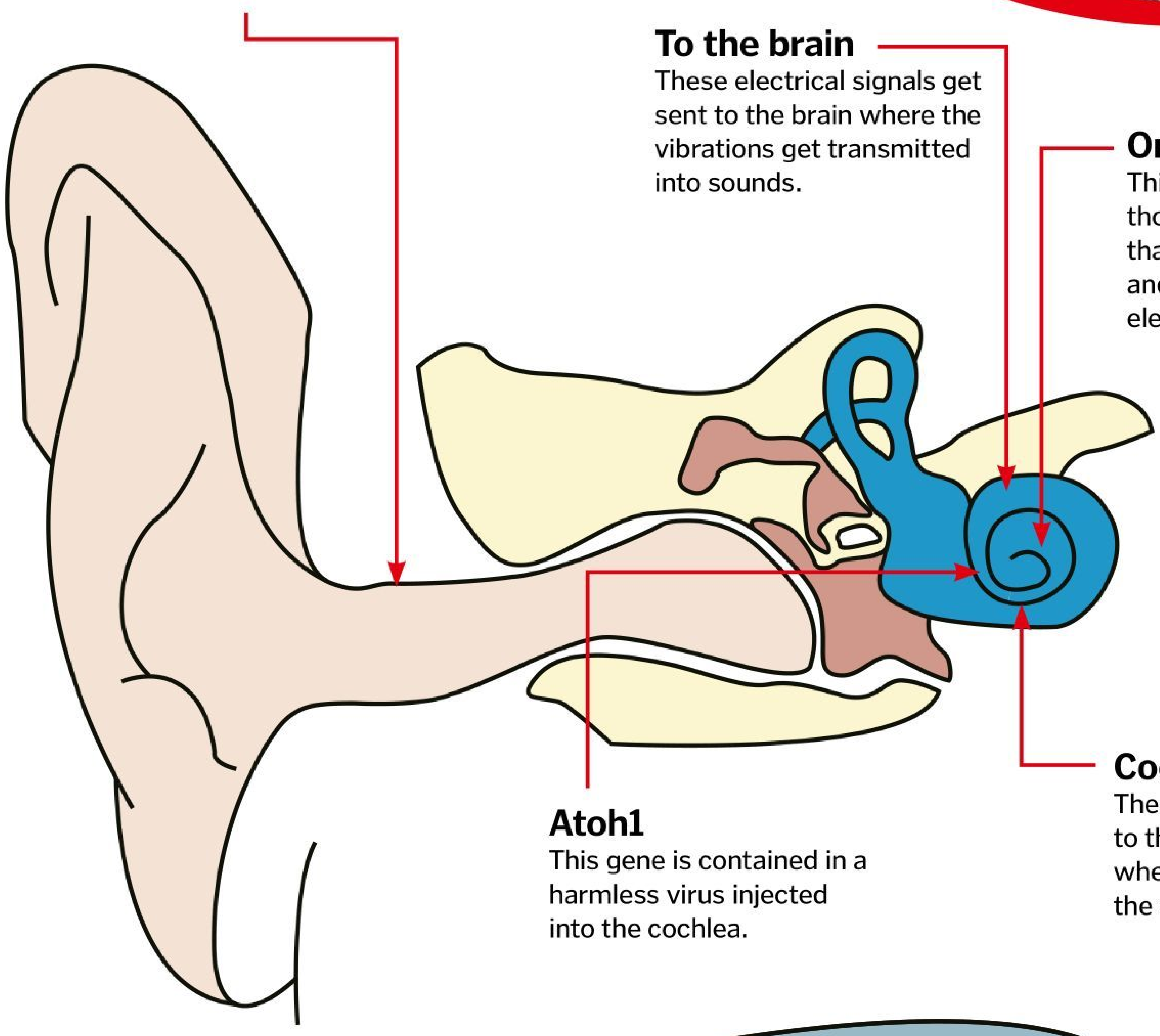
Nowadays, digital hearing aids are the norm. They are placed in the ear and a receiver registers the sound wave. A silicon chip then converts the sound waves into electrical signals, which are then released into the ear. They are basically just a way of capturing sounds the ear wouldn't have heard otherwise.

Failing that, cupping your hand behind your ear gives you an extra 12 decibels of sound, so you can try that as a small temporary boost if you're in a loud room!

Hearing loss can occur due to old age or damage to the ear

How ears work

How do our ears turn invisible waves into sound?



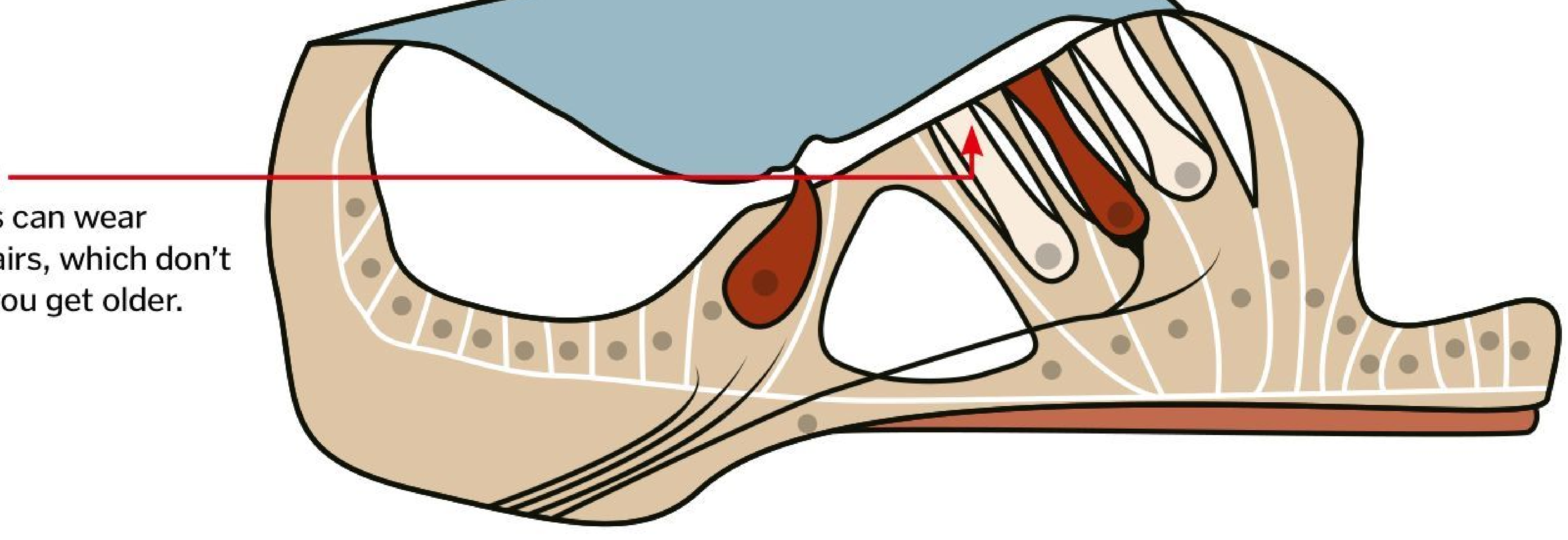
Making waves
Noise travels in waves, which enter the eardrum, either directly or guided there by the grooves in your ear.

To the brain
These electrical signals get sent to the brain where the vibrations get transmitted into sounds.

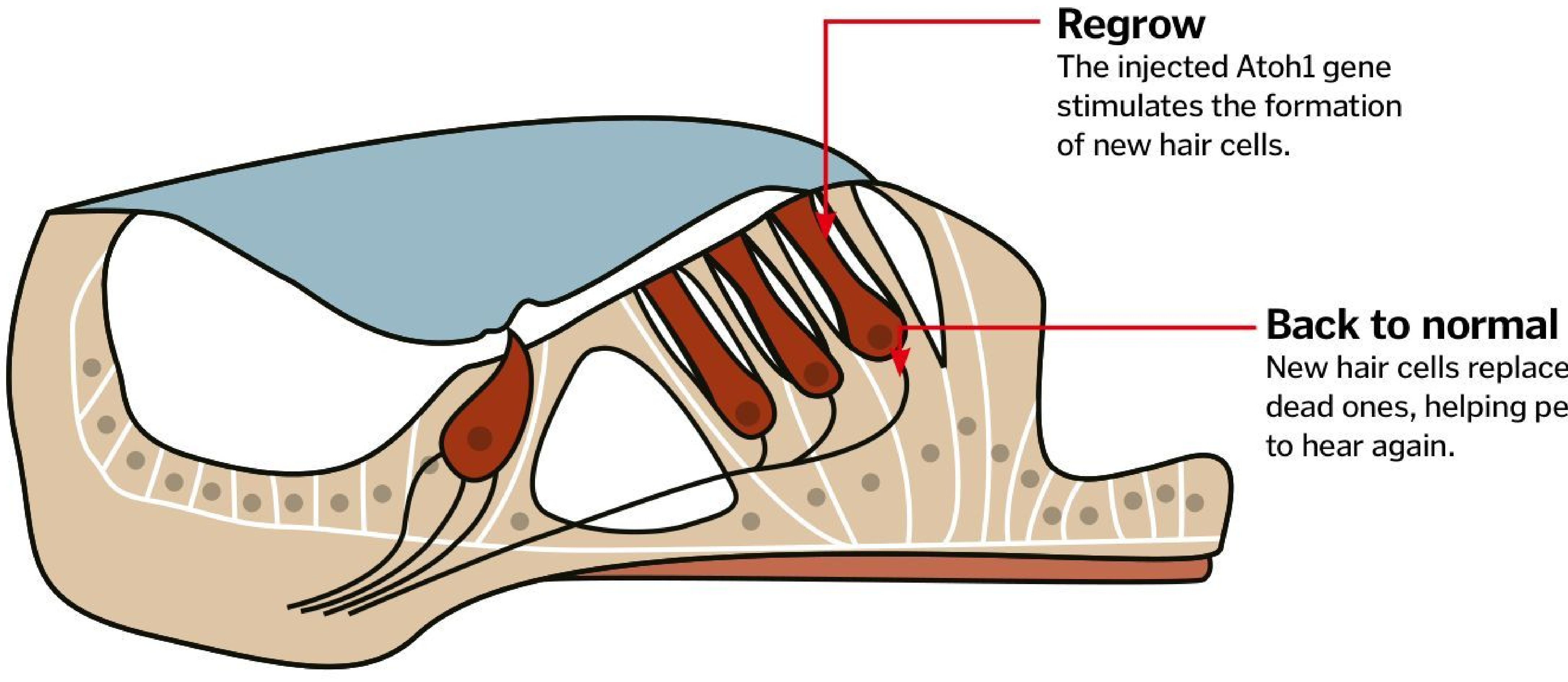
Organ of Corti
This tiny organ contains thousands of tiny hairs that sense the impulses and convert them into electrical signals.

Atoh1
This gene is contained in a harmless virus injected into the cochlea.

Cochlea
The waves move to the cochlea where they enter the organ of Corti.



Damage
Loud noises can wear away the hairs, which don't regrow as you get older.



Regrow
The injected Atoh1 gene stimulates the formation of new hair cells.

Back to normal
New hair cells replace the dead ones, helping people to hear again.

Ebola virus

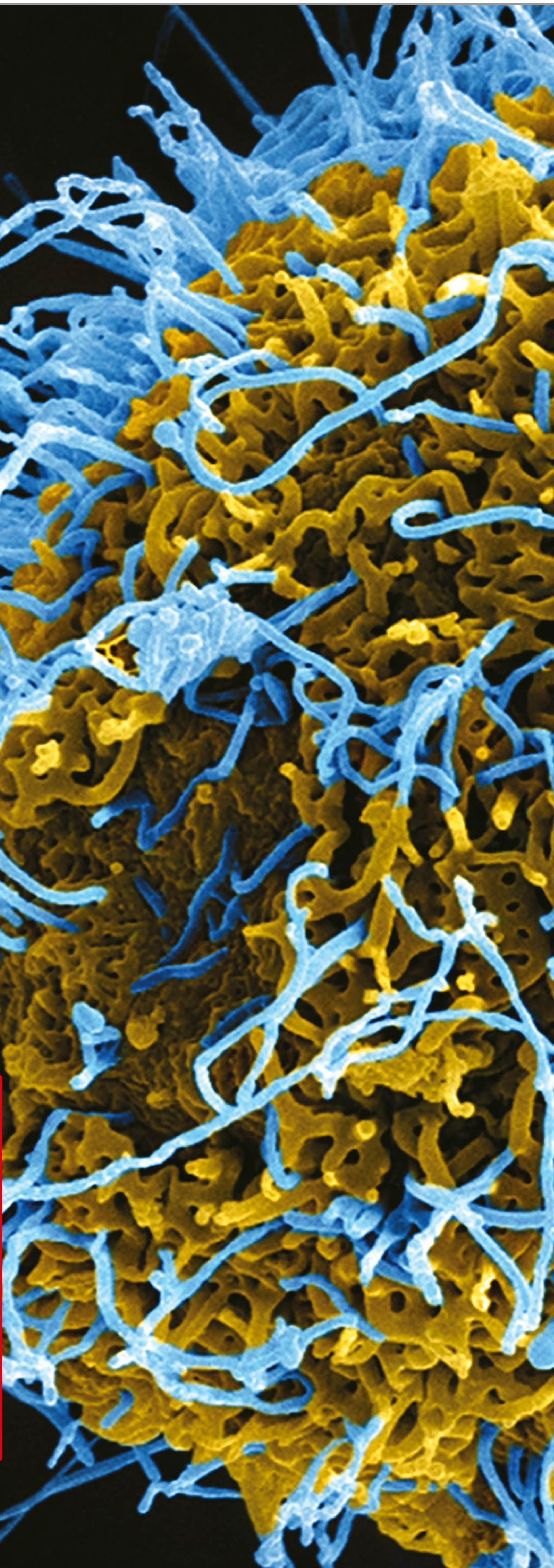
Discover how this deadly virus attacks the body and spreads between humans

The 2014 Ebola outbreak in West Africa caused thousands of deaths across Guinea, Liberia, and Sierra Leone, and led to many people feeling confused and scared about this infectious and often fatal disease.

Ebola virus disease (EVD) is spread via contact with the blood, bodily fluids and organs of an infected person or animal. A person only becomes infectious once their symptoms start to show, which is usually two to 21 days after infection. The initial symptoms are a sudden onset of fever fatigue, muscle pain, headache and sore throat, followed by vomiting, diarrhoea and rashes, eventually leading to impaired kidney and liver function, as well as internal and external bleeding.

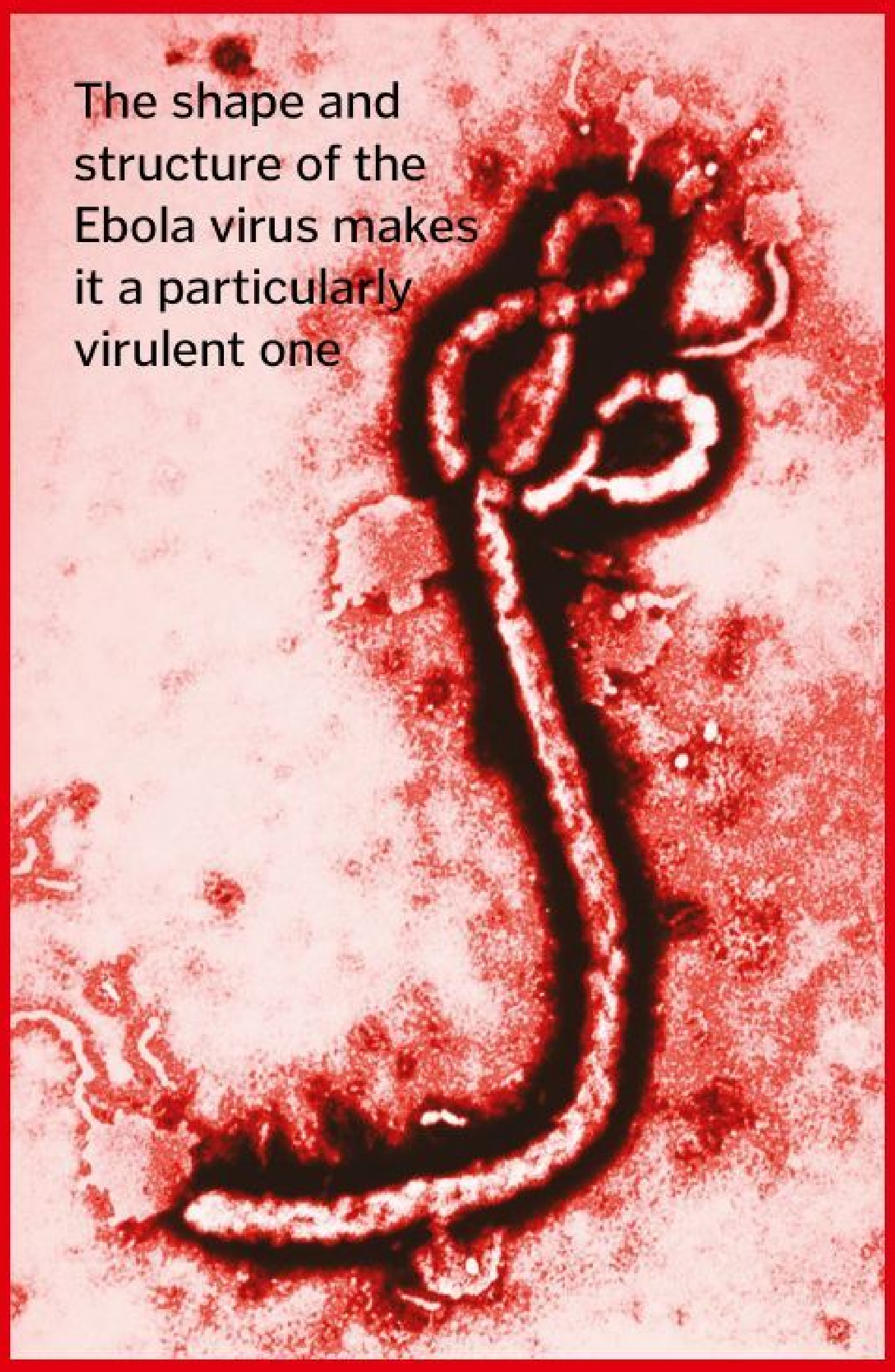
There have been many outbreaks since the disease first appeared in 1976 – when it killed nearly 300 people in the Democratic Republic of Congo, then known as Zaire – but the most recent outbreak had the highest death toll due to it spreading to urban areas instead of being contained in rural villages.

There is currently no licensed treatment for Ebola, but there are potential vaccines currently being developed and tested. However, the chances of survival are significantly improved if the body is quickly rehydrated, buying time for it to fight off infection.



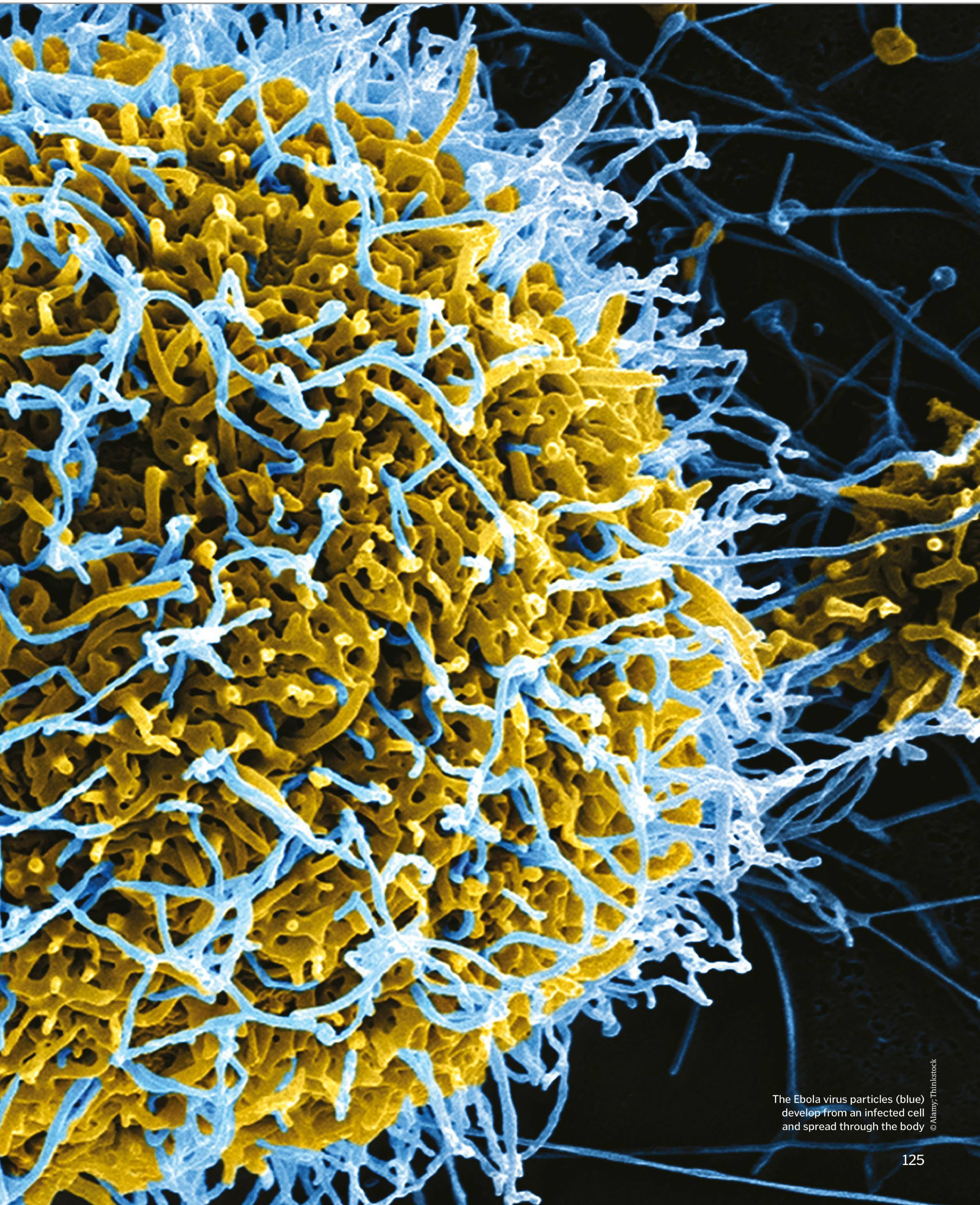
Why is Ebola so deadly?

Instead of being sphere-shaped, like most viruses, the Ebola virus is actually long and thin, giving it a larger surface area for attacking a larger number of cells. The virus is also covered in attachment proteins that bind to the receptor sites of human cells and release the virus's genetic material, allowing it to take over healthy human cells and replicate itself into new copies of the virus. Once it enters the body, it will first aim to disarm the immune system so that the white blood cells can't fight off the virus before it spreads quickly. As a haemorrhagic fever virus, the infected cells release proteins which cause blood to leak out of the vessels. This is what causes the most extreme and often fatal symptoms of Ebola, impaired kidney and liver function, a drop in blood pressure and internal and external bleeding.



The shape and structure of the Ebola virus makes it a particularly virulent one

DID YOU KNOW? *Men who have recovered from Ebola can still transmit it through their semen seven weeks after recovery*



The Ebola virus particles (blue) develop from an infected cell and spread through the body

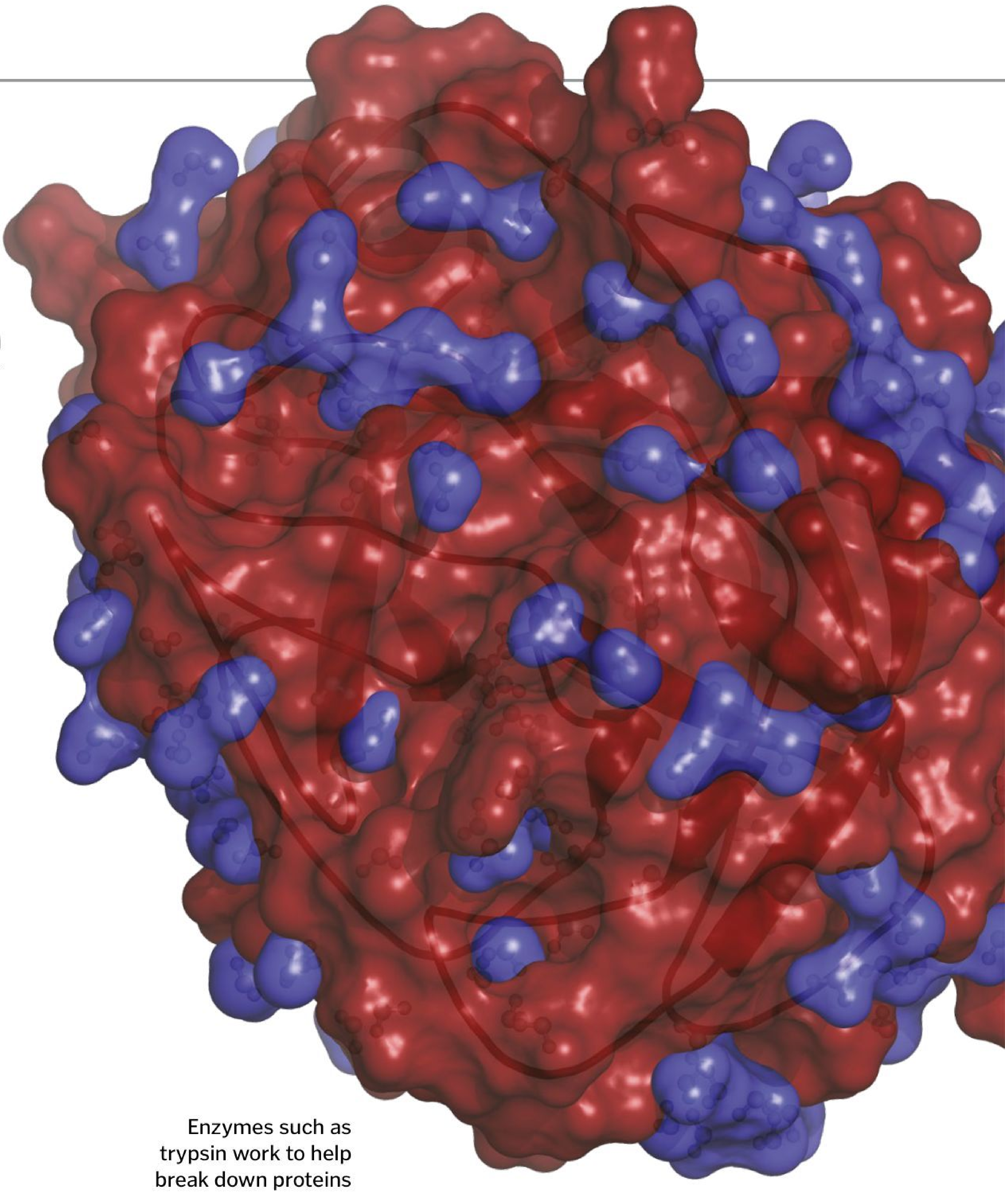
© Alamy; Thinkstock

How enzymes keep you alive

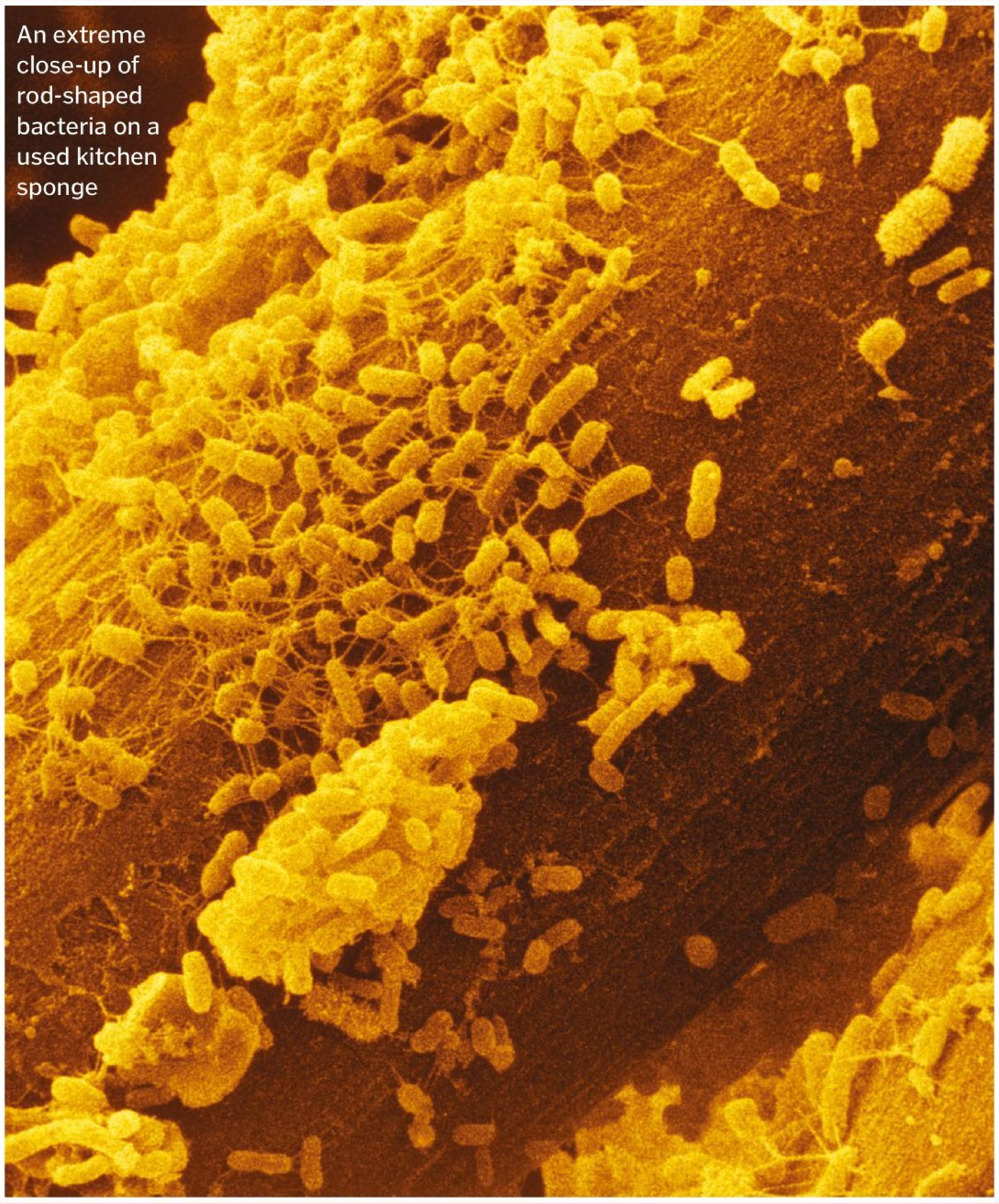
The proteins that speed up your body's chemical reactions

Enzymes increase the speed of reactions inside cells by lowering the energy-activation requirement for molecular reactions. Molecules need to react with each other to reproduce, but our bodies provide neither the heat nor the pressure required for these reactions.

Each cell contains thousands of enzymes, which are amino acid strings rolled up into a ball called a globular protein. Each enzyme contains a gap called an active site into which a molecule can fit. Once inside the crack, the molecule – which becomes known as a substrate – undergoes a reaction such as dividing or merging with another molecule without having to expel energy in a collision with another molecule. The enzyme releases it and floats on within the cell's cytoplasm. The molecule and active site need to match up perfectly in order for the sped-up reaction to take place. For example, a lactose molecule would fit into a lactase enzyme's active site, but not that of a maltase enzyme. Interestingly enough, enzymes don't get used up in the process, so they can theoretically continue to speed up reactions indefinitely.



Enzymes such as trypsin work to help break down proteins



An extreme close-up of rod-shaped bacteria on a used kitchen sponge

Bacteria explained

Find out how these microorganisms can survive anything

These single-celled microorganisms are often referred to as microbes due to their ability to spread diseases. Unlike other organisms, they do not have a membrane-bound nucleus, but rather a single DNA loop that stores genetic information.

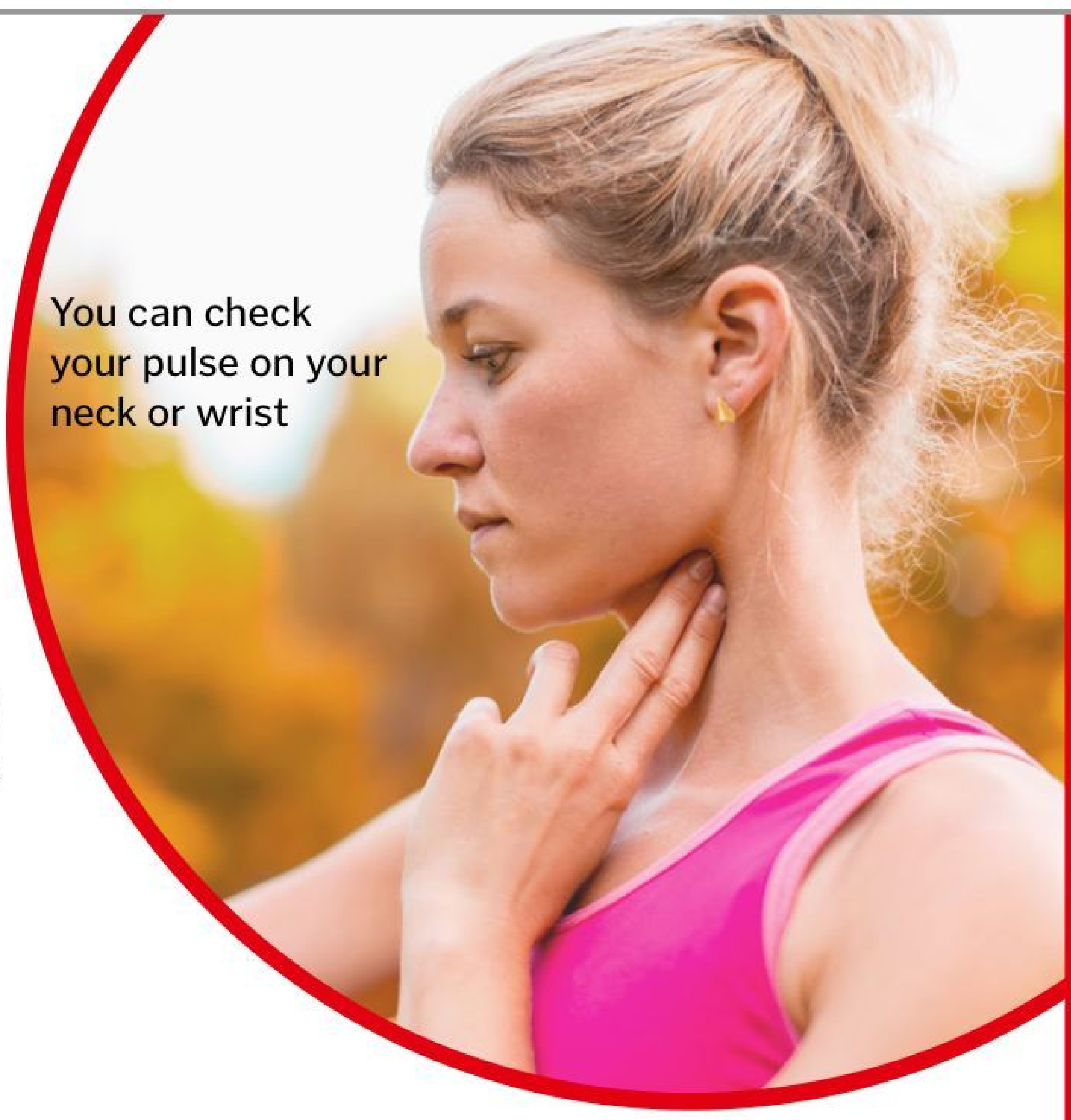
Although just a few micrometres in length and therefore too small to see with the naked eye, bacteria certainly make up for their size and seemingly simple cell structure by being rather complex little creatures. First, they can survive absolutely anywhere. Although they have different survival requirements depending on their habitats, bacteria adapt to their environment. From boiling hot springs to sub-zero temperatures; whether deep below the Earth's surface or high up in its atmosphere, as long as they have nutrients to grow and reproduce, they can withstand conditions that no human ever could.

Bacteria reproduce when the bacterium splits into two identical daughter cells. Known as binary fission, this process can occur at an incredible rate. This can be dangerous when the bacterium is pathogenic and is why diseases can spread so quickly.

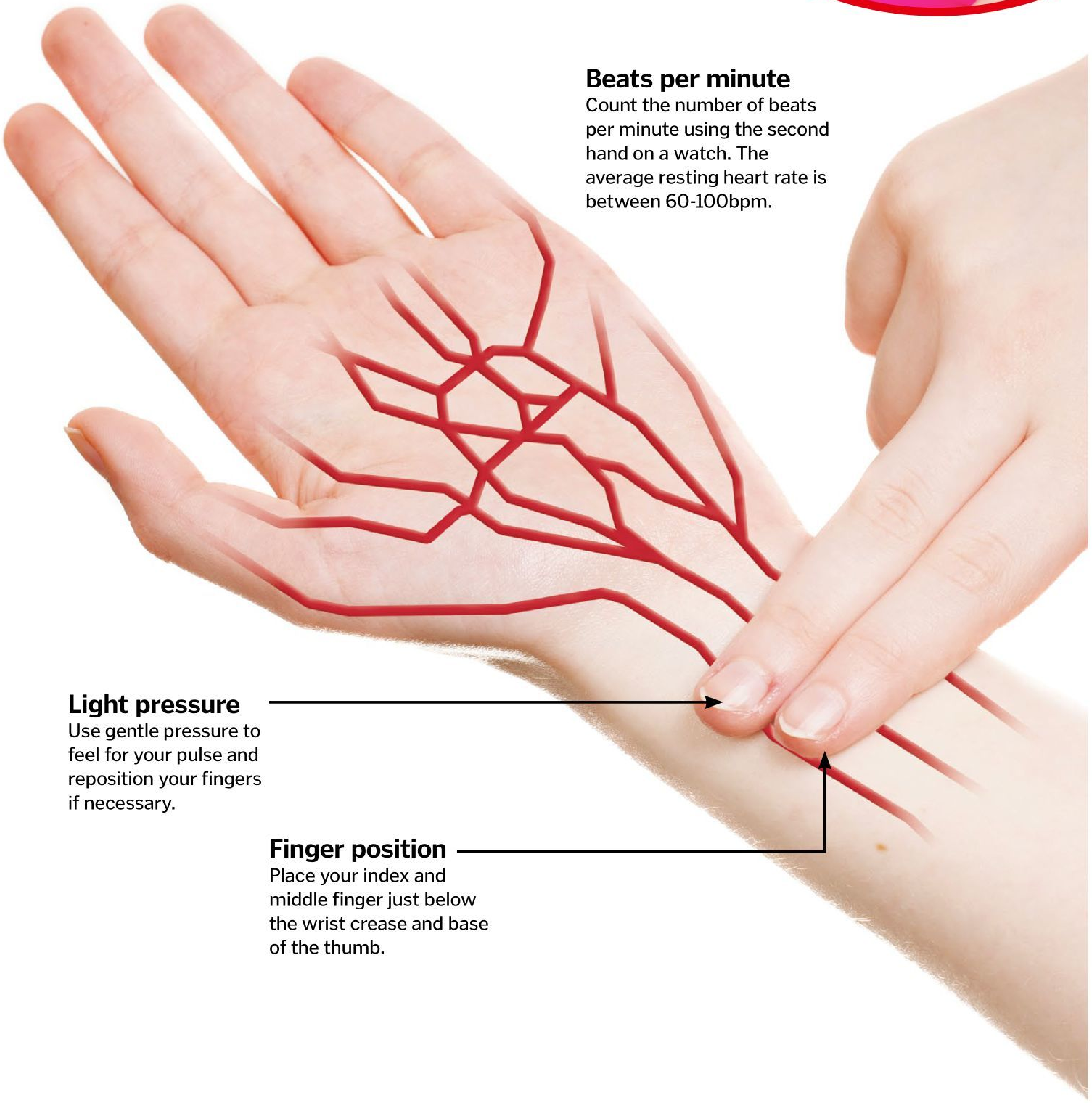
© Thinkstock; Science Photo Library

How to check your pulse

See whether you have a regular or irregular heart rate



You can check your pulse on your neck or wrist



Beats per minute
Count the number of beats per minute using the second hand on a watch. The average resting heart rate is between 60-100bpm.

Light pressure
Use gentle pressure to feel for your pulse and reposition your fingers if necessary.

Finger position
Place your index and middle finger just below the wrist crease and base of the thumb.

Checking your own pulse is a good way to keep track of your heart rate. Monitoring it while you're resting is the best way to get an accurate reading, as rhythm can increase at different times during the day, especially when you're exercising.

It's possible to check your radial pulse on your wrist or on your neck. This is because arteries pass close to the skin in these areas. To take your wrist pulse, simply turn over one of your hands so that the palm is facing up. Now place the index and middle finger from your other hand below the crease of the wrist, in line with the base of your thumb and next to the tendon. Use gentle pressure and feel carefully for a beating pulse. If you're checking your pulse in your neck, place the same two fingers just below the jawline next to your windpipe.

Once you've located your pulse, use the second hand on a watch to count the number of beats per minute. A normal resting heart rate for an adult should be around 60 to 100 beats per minute.

Keeping hydrated

Why is it important to drink enough water?

About 60 per cent of a typical adult human's body weight is water and it is vital for transporting carbohydrates, vitamins, minerals and oxygen to the cells and carrying waste away. This helps to keep the brain alert, absorb nutrients from food into the bloodstream, filter out waste products through urine, regulate blood pressure and body temperature and lubricate the muscles and joints. Water leaves your body through sweat, urine and even your breath, so must be replenished by drinking regularly.

The amount of water you need to consume depends on a number of factors, including your age, the ambient temperature and how much you exercise. However, it is recommended that a typical adult should drink two litres (0.5 gallons) of water per day. About 80 per cent of this intake usually comes from our drinks, while the other 20 per cent comes from water content in food. Even if you lose just one per cent or more of your body weight through fluid loss, you become dehydrated. If you don't replenish your body's fluid levels within 24 hours then you will start to suffer severe reduction in your physical and cognitive performance.

Drinking water is the best method of hydration as it contains no sugar, calories or additives

Understanding diabetes

Peek inside the body to see what happens when blood sugar gets out of control

Gorging on a rich, moist piece of chocolate cake is a guilty pleasure for many, but people with diabetes have to think twice before taking a bite. Diabetes is a long-term medical condition where the body can't process sugar in the bloodstream properly, so sweet treats can be dangerous for more than just their waistline.

Sugar in the blood comes from what we eat and drink and is regulated by the hormone insulin, which is produced by the pancreas. This organ is about 15 centimetres long and located behind the stomach. The pancreas mainly secretes digestive enzymes, but a small part produces hormones. Insulin is produced by beta cells, which are clustered in groups called the islets of Langerhans (named after the scientist who first described them).

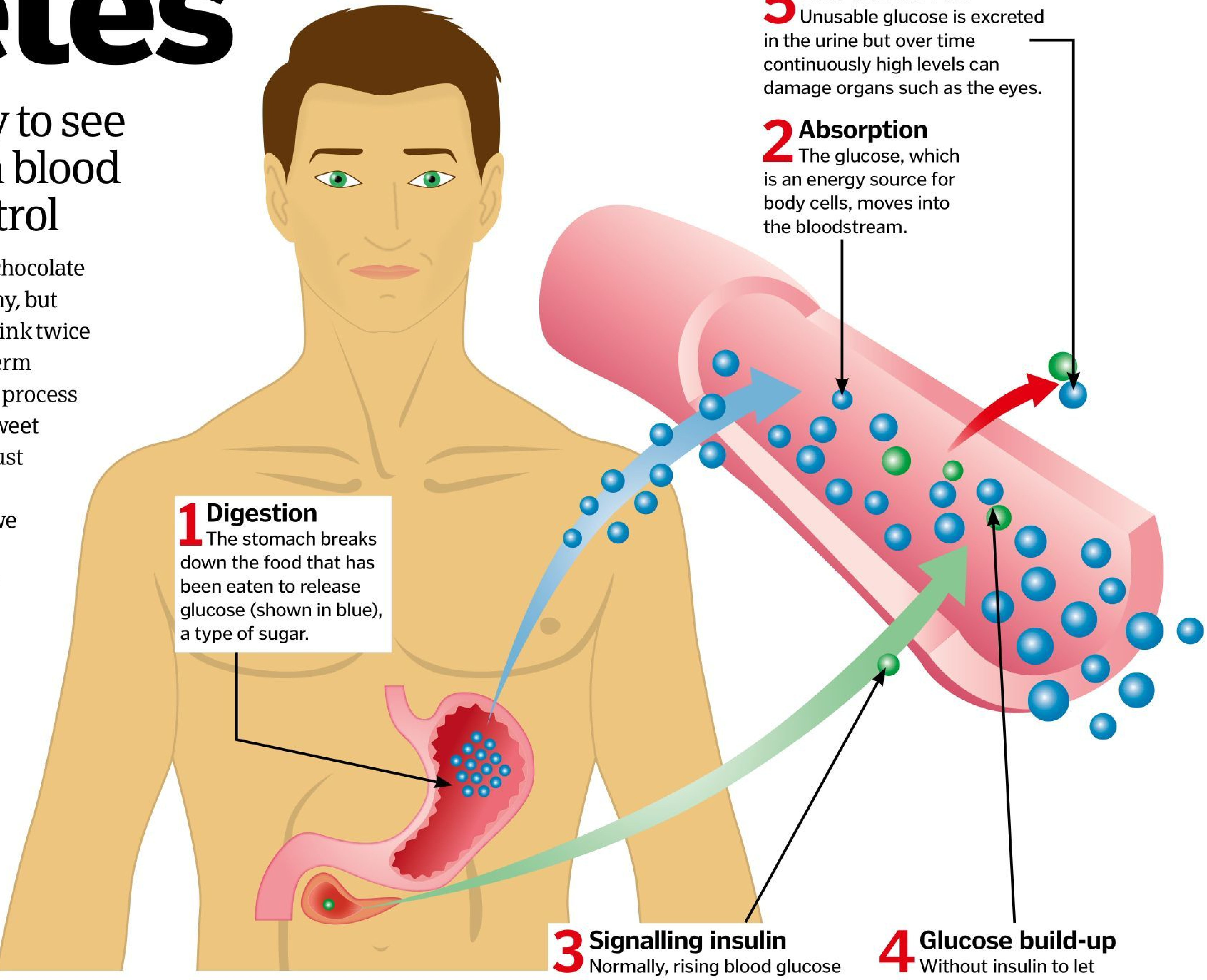
In diabetes, the normal process of producing insulin and regulating blood sugar goes awry. This can happen in two different ways. In type 1 diabetes, the pancreas doesn't produce any insulin because the body's immune system attacks the beta cells and kills them. In type 2, not enough insulin is produced, or the body becomes resistant to insulin and is unable to respond to it. Both types can lead to high blood sugar levels called hyperglycaemia, which can damage the eyes, kidneys, nerves and blood vessels over time.

The symptoms for both types of diabetes include extreme thirst, urinating more frequently, tiredness, unexplained weight loss, blurred vision and the slow healing of cuts. Both types can develop at any age, but type 2 diabetes is much more common, and is often associated with obesity.

There is currently no cure for diabetes. People with type 1 diabetes have to control their blood sugar for the rest of their lives by monitoring the levels and injecting insulin. People with type 2 diabetes have to make lifestyle changes, and often need to take medication.

Type 1 diabetes

When the pancreas doesn't make insulin, glucose hangs around in the blood



5 Extreme levels Unusable glucose is excreted in the urine but over time continuously high levels can damage organs such as the eyes.

2 Absorption The glucose, which is an energy source for body cells, moves into the bloodstream.

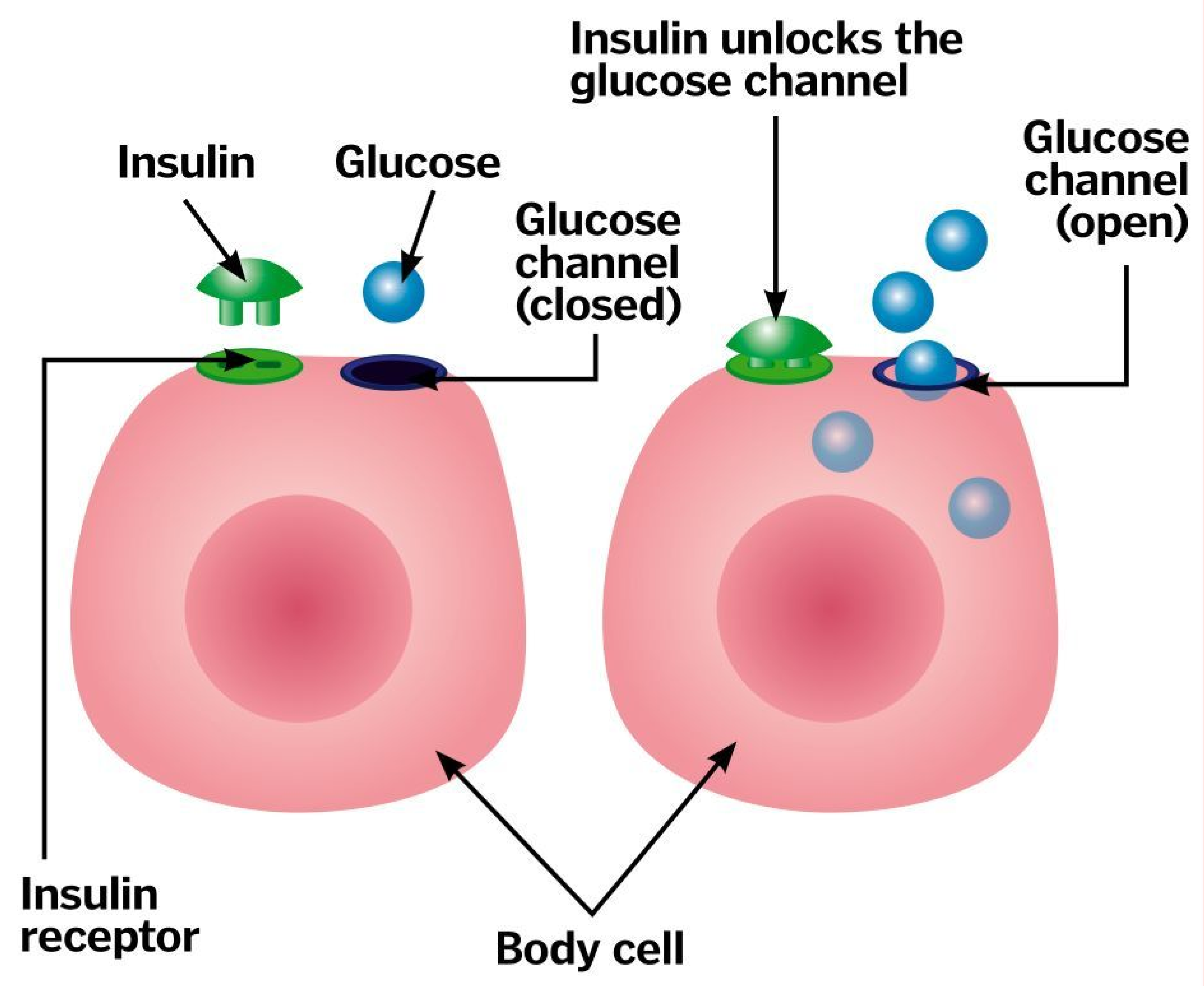
1 Digestion The stomach breaks down the food that has been eaten to release glucose (shown in blue), a type of sugar.

3 Signalling insulin Normally, rising blood glucose would be detected and the pancreas would produce insulin (shown in green), but in type 1 diabetes no insulin is produced.

4 Glucose build-up Without insulin to let the glucose into cells, the glucose levels in the blood build up, leading to hyperglycaemia.

How insulin works

Sugar, in its simplest form as glucose, is an energy source for our body's cells. It moves into cells most efficiently when a signal is given by the hormone insulin. When blood glucose rises after a meal, insulin is released from the pancreas into the bloodstream and acts like a key to unlock and open the glucose channels on the cell surface, allowing glucose to enter. When there is no insulin or the cells can't respond to it, the levels of sugar in the blood build up, leading to hyperglycaemia. Conversely, when blood glucose gets too low, it is known as hypoglycaemia.



DID YOU KNOW? *3.5 million people in the UK are diagnosed with diabetes, and a further 549,000 have it but are not yet diagnosed*

Diabetes and exercise

Exercise can cause blood glucose levels to fluctuate, though this is less drastic in people with type 2 diabetes than those with type 1. Low blood sugar (hypoglycaemia) can occur because muscles use glucose as energy and the body becomes more sensitive to insulin. High blood sugar (hyperglycaemia) can be triggered by other hormones, such as adrenaline, which are released during exercise.

Maintaining an optimal blood sugar target in type 1 diabetes requires balancing the insulin dose with what the person eats and drinks and the amount of exercise they do, taking into account external factors like temperature. Everyone's diabetes is different and individuals react differently to exercise. Physical activity, however, can help improve blood glucose management and the efficient working of insulin.

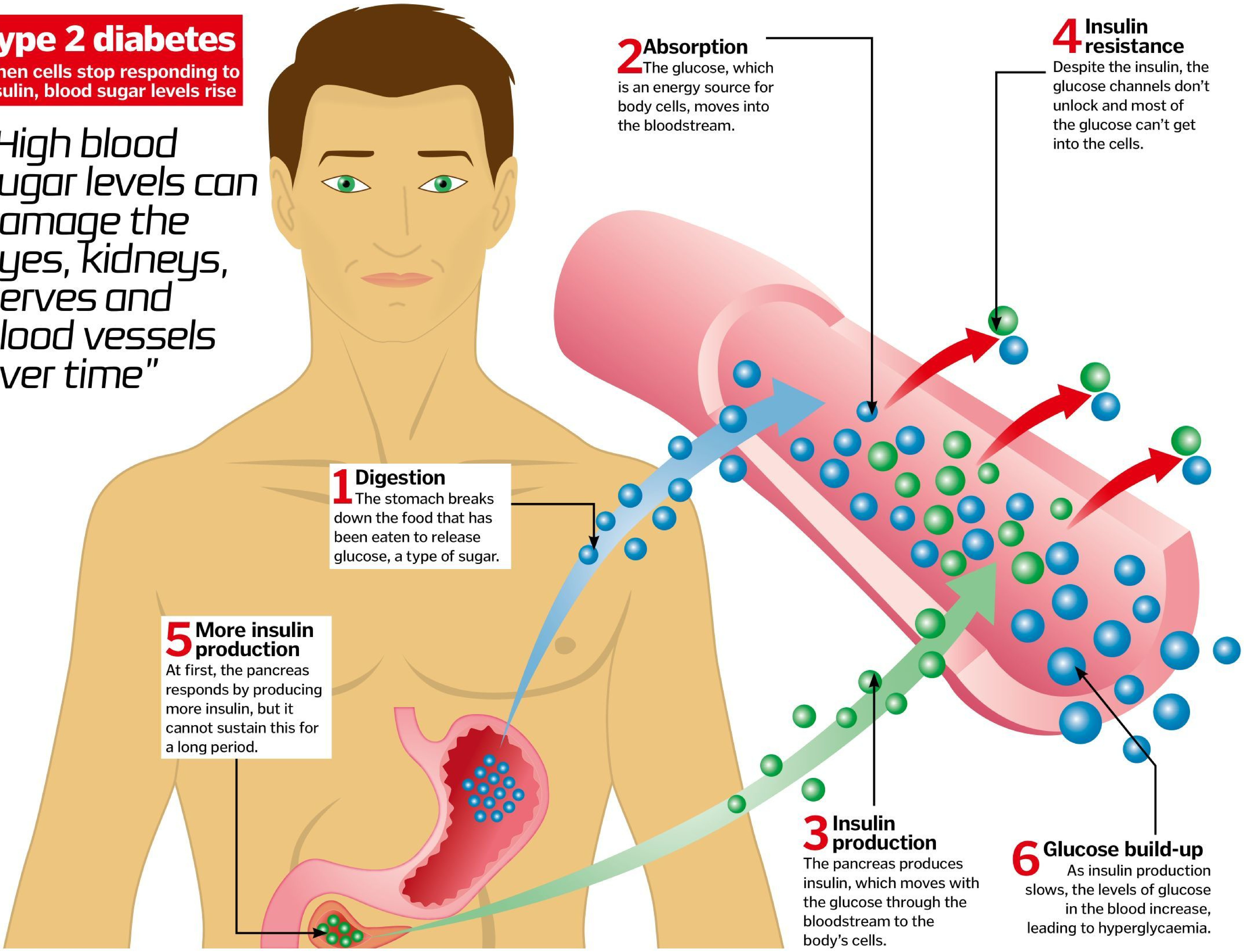
Cycling is a physically challenging endurance sport and Team Novo Nordisk, an all-diabetes pro-cycling team, must monitor their blood glucose before, during and after racing with a continuous glucose monitor. The cyclists will 'carb-load' (eat high carbohydrate foods) before a race and will have a high-carbohydrate drink afterwards. During a race, riders frequently check their blood glucose. If their blood sugar is above target, they may take medication to lower it, and if the level is below target, they may consume a carbohydrate-rich food or drink to bring it back up.

Athletes with diabetes, like the members of Team Novo Nordisk, monitor blood glucose before, during and after exercise

Type 2 diabetes

When cells stop responding to insulin, blood sugar levels rise

> *"High blood sugar levels can damage the eyes, kidneys, nerves and blood vessels over time"*



1 Digestion
The stomach breaks down the food that has been eaten to release glucose, a type of sugar.

2 Absorption
The glucose, which is an energy source for body cells, moves into the bloodstream.

3 Insulin production
The pancreas produces insulin, which moves with the glucose through the bloodstream to the body's cells.

4 Insulin resistance
Despite the insulin, the glucose channels don't unlock and most of the glucose can't get into the cells.

5 More insulin production
At first, the pancreas responds by producing more insulin, but it cannot sustain this for a long period.

6 Glucose build-up
As insulin production slows, the levels of glucose in the blood increase, leading to hyperglycaemia.

Perfect posture

Find out how being a serial sloucher affects more than just your spine

Chances are most of you reading this aren't sitting or standing properly. Students and office workers know only too well how easy it is to slip into a slouch while spending all day working at a desk. This prolonged poor posture puts stress on the neck, shoulders and spine, contributing to problems such as postural hunchback and spinal misalignment.

Good posture ensures that you can stand, sit or lie down in positions that put the least strain on your body's muscles and ligaments. A quick way to check your posture is to make sure your earlobes are aligned over the middle of your shoulders, your shoulders are in line with your hips, and your hips are directly above your knees and ankles. This correct positioning may take some practice, but as you retrain your muscles it becomes second nature.

In addition to putting stress on your bones and muscles, bad posture affects how efficiently we breathe. Hunching the shoulders restricts the amount by which the rib cage can expand, reducing lung capacity by as much as 30 per cent. Poor posture has also been linked to neurological issues and heart disease.

A surprising side effect of posture is that it can change how people think. A study by Ohio State University in the US found that people who sat up straight exhibited a more confident and positive outlook than those who slumped over.

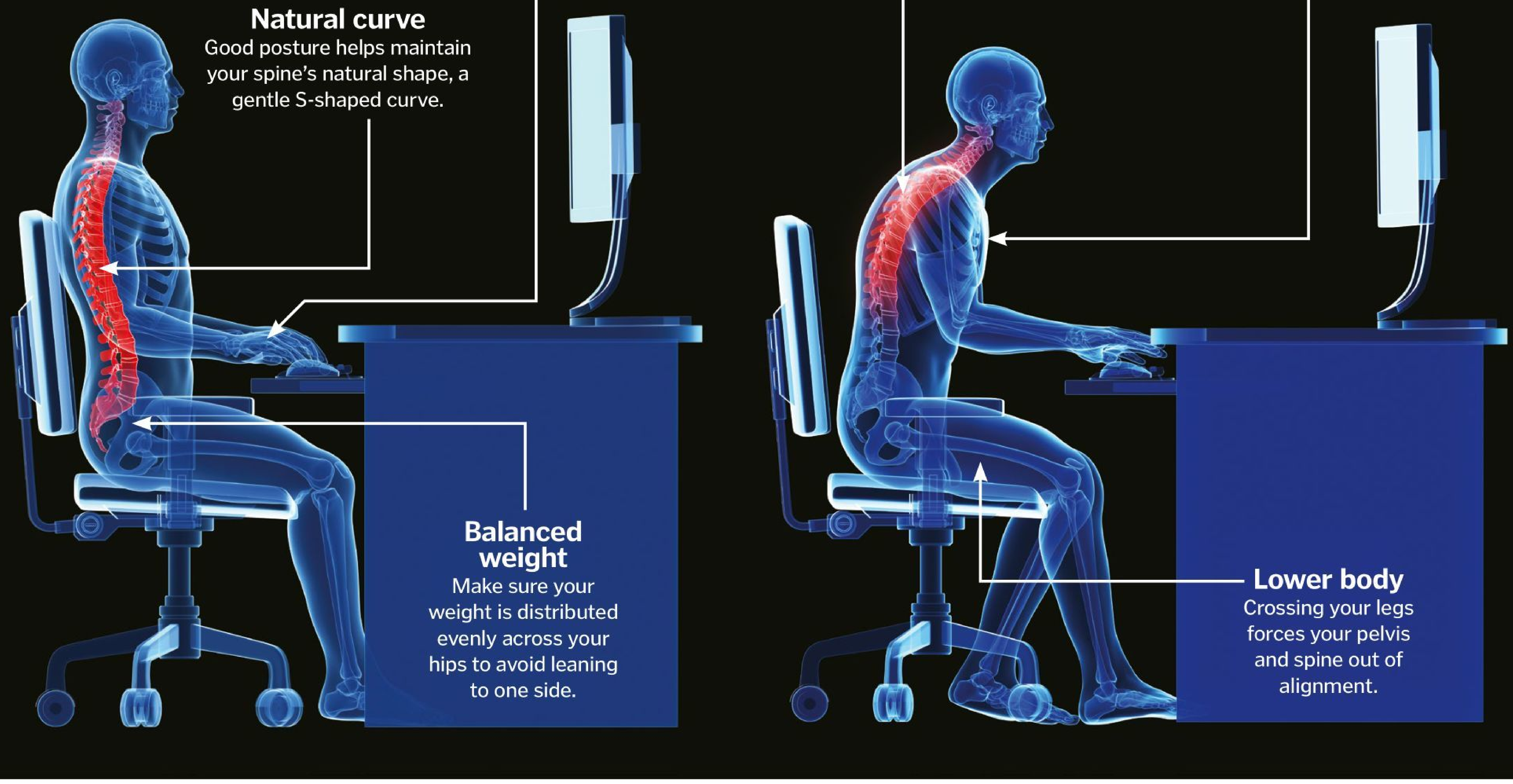
Whether standing or sitting, maintaining good posture is important for your health

Sit-stand desks

With research highlighting the negative health effects of sedentary lifestyles, sit-stand desks like the Varidesk are becoming more popular. These adjustable platforms make it easy to alternate between sitting and standing throughout the day, to avoid staying fixed in the same position for hours at a time. Find out more at **www.varidesk.com**.

Seated posture

How sitting up straight protects your spine



Arms
Avoid resting your weight on your forearms or elbows, as this can strain your shoulders and upper back.

Strain
Bad posture works against the natural curvature of your spine, putting stress on the muscles.

Hunching over
Spending hours hunched over a desk can tighten your chest and weaken your upper back.

Natural curve
Good posture helps maintain your spine's natural shape, a gentle S-shaped curve.

Balanced weight
Make sure your weight is distributed evenly across your hips to avoid leaning to one side.

Lower body
Crossing your legs forces your pelvis and spine out of alignment.

Breaking bad habits

Most of us are guilty of these common posture mistakes, but luckily they can be corrected

Slouching

Reclining with no lower back support can feel comfortable as it requires less muscular effort, but over time this puts pressure on some muscles while weakening others.

'Donald Duck' posture

Frequently wearing high heels or being pregnant can pitch your weight forward, so your upper body leans forward of your hips and your bottom sticks out.

Jutting chin

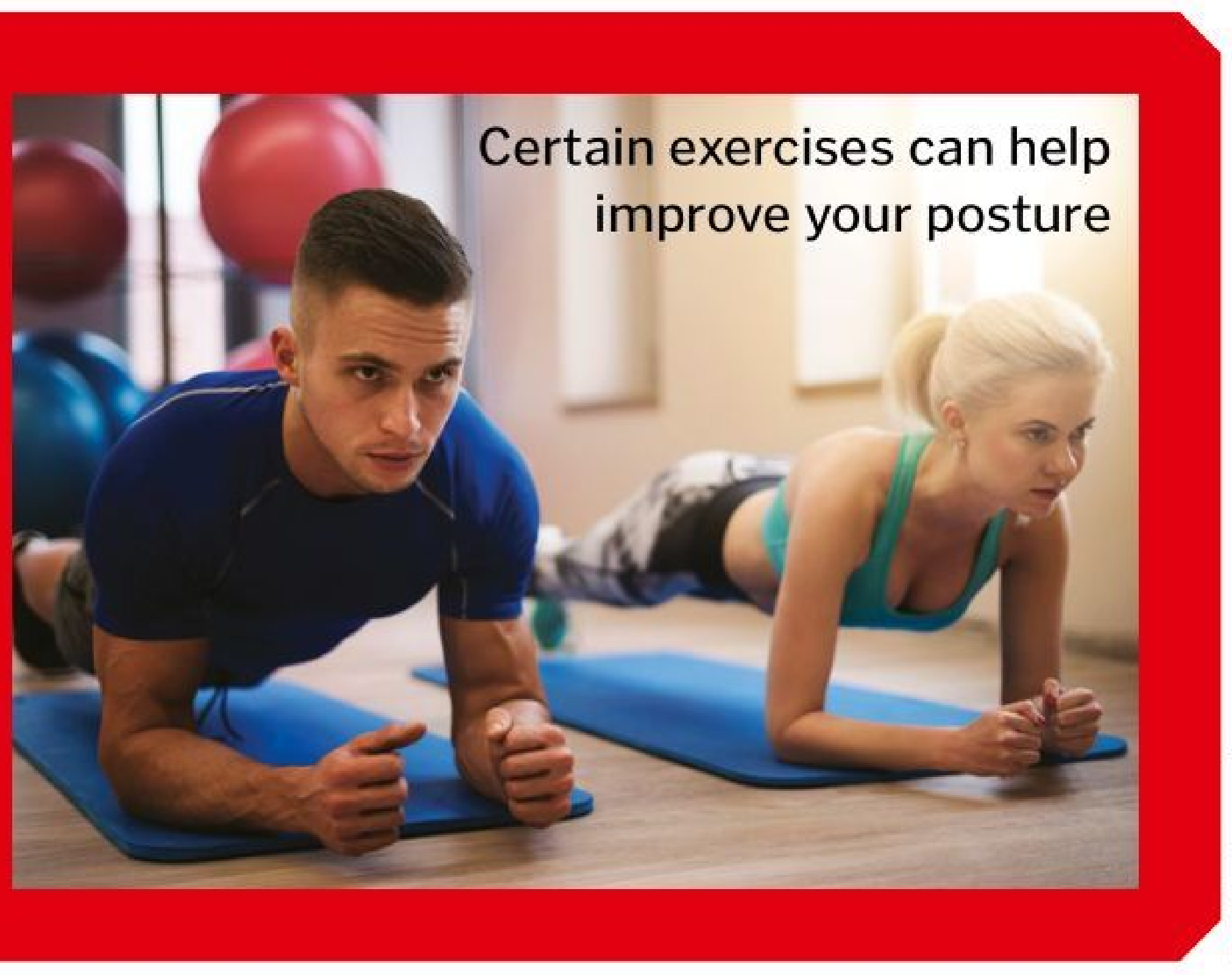
Poking your chin out when viewing a screen is a by-product of poor posture. Hunched shoulders angle the neck and head down, so the chin is lifted to keep looking forward.

Standing on one leg

Leaning on one leg, rather than having your weight evenly distributed between both of them, puts extra pressure on one side of your lower back and hips.

THE SOLUTION

Practice makes perfect! Consciously correcting your posture will help improve it over time. Strengthening your core with exercises like back extensions and planks will also help re-train weakened muscles.



Certain exercises can help improve your posture

© Thinkstock

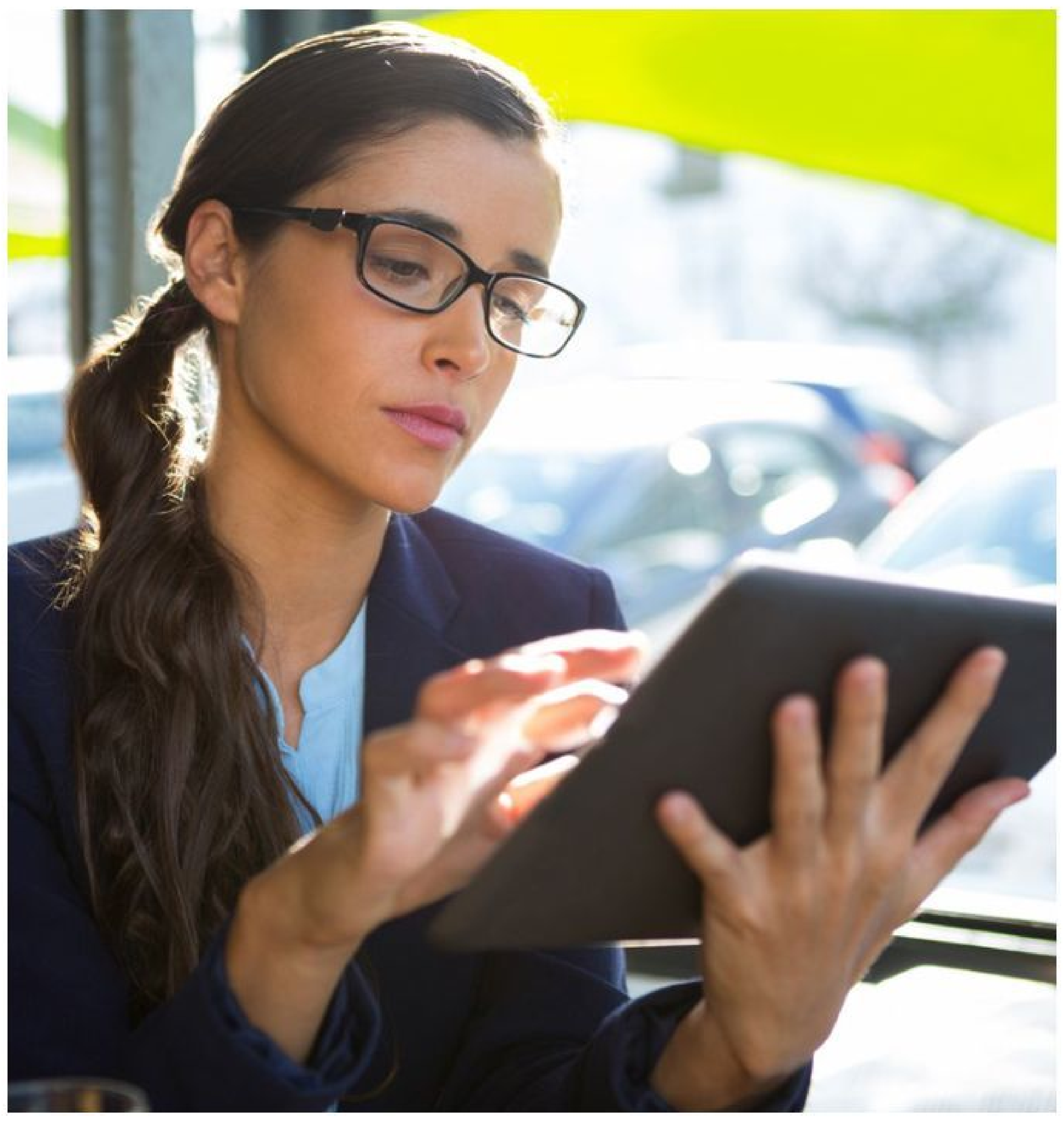
DID YOU KNOW? *Corrective lenses are prescribed by someone called an optometrist*

How corrective lenses work

An important tool for sight deficiencies, corrective lenses restore 20/20 vision and reduce eye strain

In optics, a lens is a transparent substance (usually glass) that is used to form an image of an object by focusing rays of light to a designated point. In eyeglasses, lenses are used to correct a wide variety of eye defects including myopia, hyperopia and astigmatism. This is achieved by shaping the lenses into various optical profiles, the most common of which is ophthalmic convex-concave. Here, both the front and back of the lens surface has a positive radius, resulting in a convergent front surface and divergent back surface. This difference creates the corrective power of the lens, so in order to treat hyperopia a convergent lens is used, where the front surface is stronger than the rear (narrowing the incoming light's focus); for myopia, the reverse is used, with the rear surface holding a greater magnitude (widening the light's focus point).

Modern corrective lenses can be formed with multiple spherical surfaces, granting them a highly complex profile. This allows bifocal and trifocal lenses to be produced, where different parts of the lens are shaped and hold powers suitable for various distances of focus.



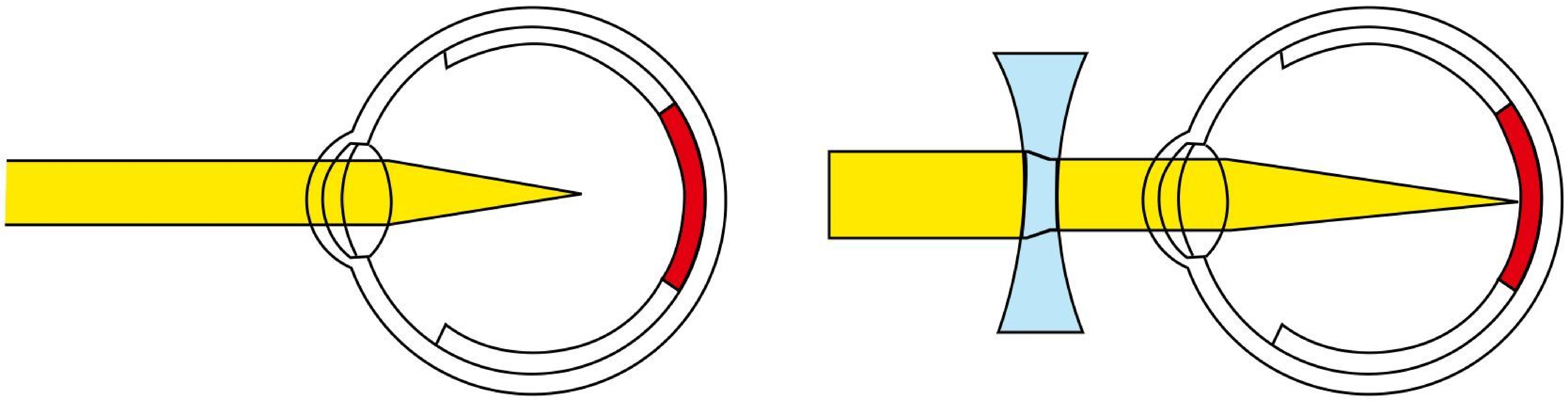
Pinhole glasses

How do these lens-less glasses help correct vision?

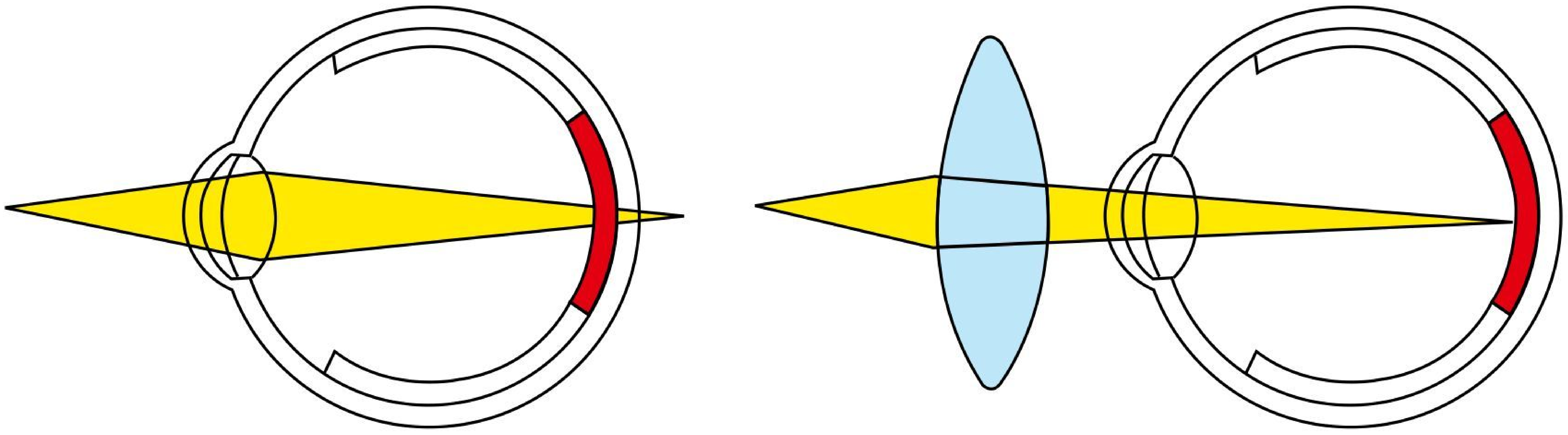
Pinhole glasses – technically called stenopeic glasses – are eyeglasses that consist of two plastic opaque sheets filled with a series of pinhole-sized holes. These perforated sheets replace the lenses of the glasses and, when worn, reduce the amount of light entering each eye to a series of narrow beams. This reduction in light reduces the circle of confusion (an optical blur spot) on the eyes' retina, while also increasing depth of field. Unlike lens-based glasses though, pinhole glasses produce an image without generating a pincushion distortion (an effect where image magnification increases with the distance from the optical axis, as seen in binoculars). In essence, stenopeic glasses work on the same principle of pinhole cameras, producing a sharper image but at the expense of brightness.

© Nummerg

How lenses can be used to treat myopia and hyperopia



Myopia (short-sightedness)
A refractive defect of the eye in which collimated (parallel) light is forced to produce images in front of the retina instead of upon it, myopia is treated through the use of a concave lens. This causes incoming light to enter the cornea at a different angle and diverge on the retina.



Hyperopia (long-sightedness)
A vision defect usually caused by the eyeball being too short or its cornea not being rounded enough during development, hyperopia causes difficulty in focusing on near objects. It is treated by the application of a concave lens, which adjusts the focus of incoming light so it accurately displays on the retina.

Inside laser eye surgery

How surgeons are able to restore your sight with lasers

Lasers have been used to help people with short and long-sightedness (or myopia and hyperopia) for a couple of decades, but the practice of using incisions in a person's eye to improve their vision has been around for over 100 years.

It all started in 1898 when eye surgeons would make small cuts in the front surface of the eye (cornea), to flatten it in the middle and let light reach the retina more easily. As this technique was a bit hit-and-miss, they came up with a new technique that involved using a thin blade to slice open the cornea and create a flap. The eye surgeon would then slice a bit of tissue from the cornea to flatten it as before and then fold the flap back down.

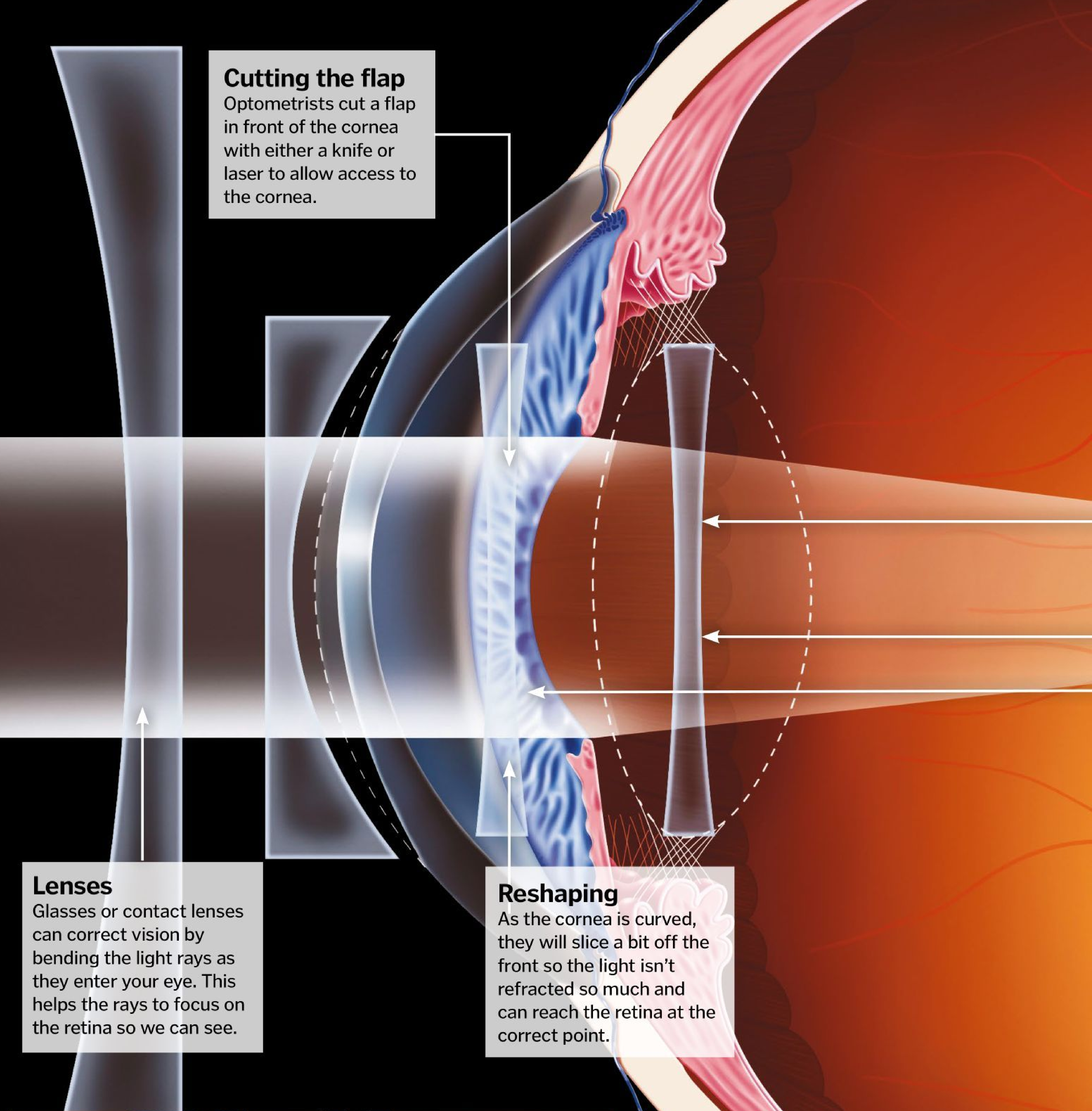
The technology took a huge leap forward when they brought lasers into the equation. These super-precise beams were able to burn away part of the cornea without creating a flap, but this did lead to a very long and uncomfortable recovery.

Then, in 1999, LASIK entered the arena. This procedure, combining two previous methods, required a flap to be made and then the laser could get to work with shaping the stroma layer of the cornea. This allowed for more precision than ever before and vastly reduced the discomfort from the previous method.

The actual surgery takes a surprisingly short amount of time. From the point at which the numbing drops get popped in, the creation of a flap, reshaping and replacing it should take between 15 and 30 minutes, with full vision returning within 24 hours.

A look inside the eye

How does surgery correct a short-sighted eyeball?



Cutting the flap
Optometrists cut a flap in front of the cornea with either a knife or laser to allow access to the cornea.

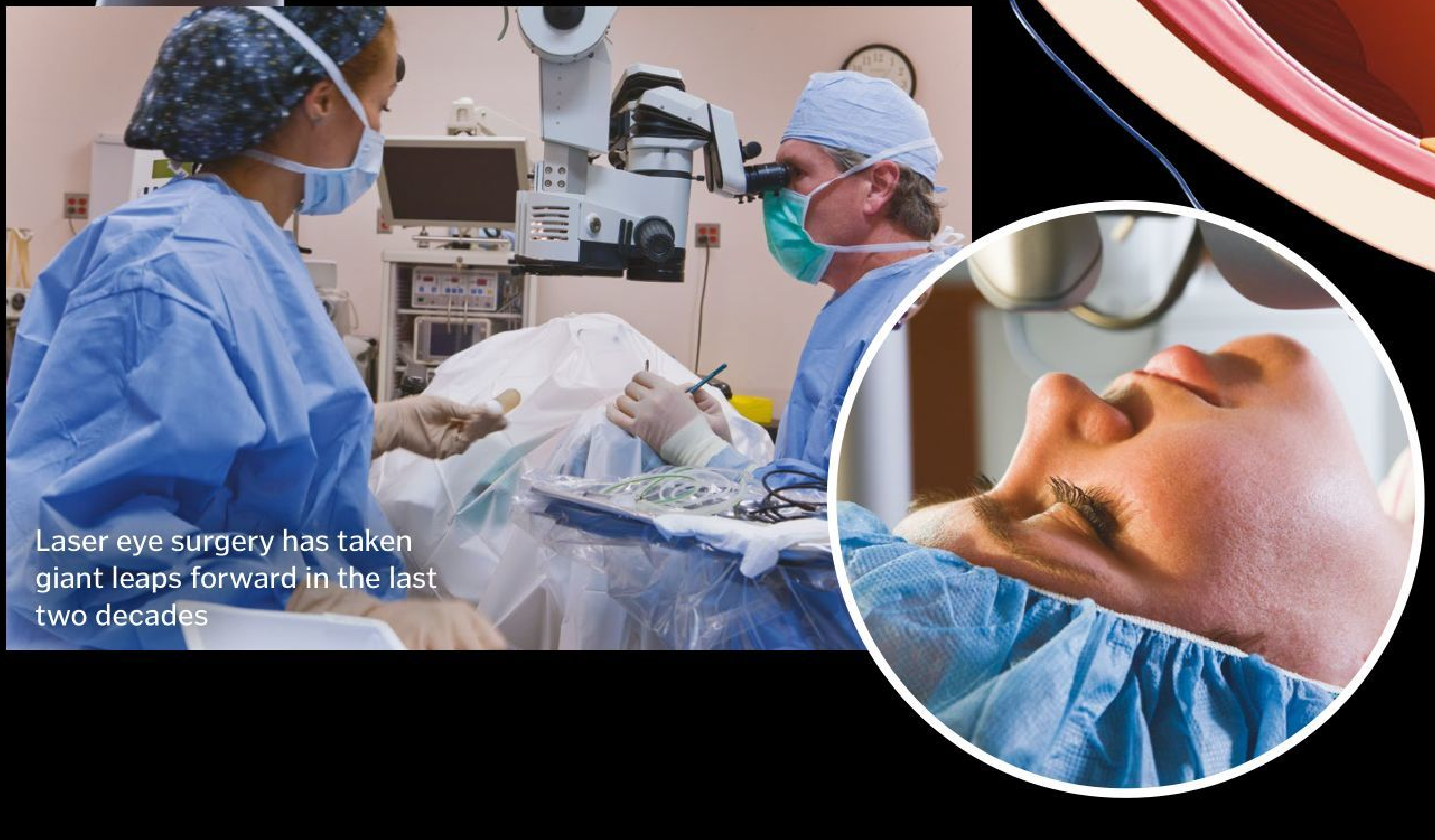
Lenses
Glasses or contact lenses can correct vision by bending the light rays as they enter your eye. This helps the rays to focus on the retina so we can see.

Reshaping
As the cornea is curved, they will slice a bit off the front so the light isn't refracted so much and can reach the retina at the correct point.

What else can laser eye surgery do?

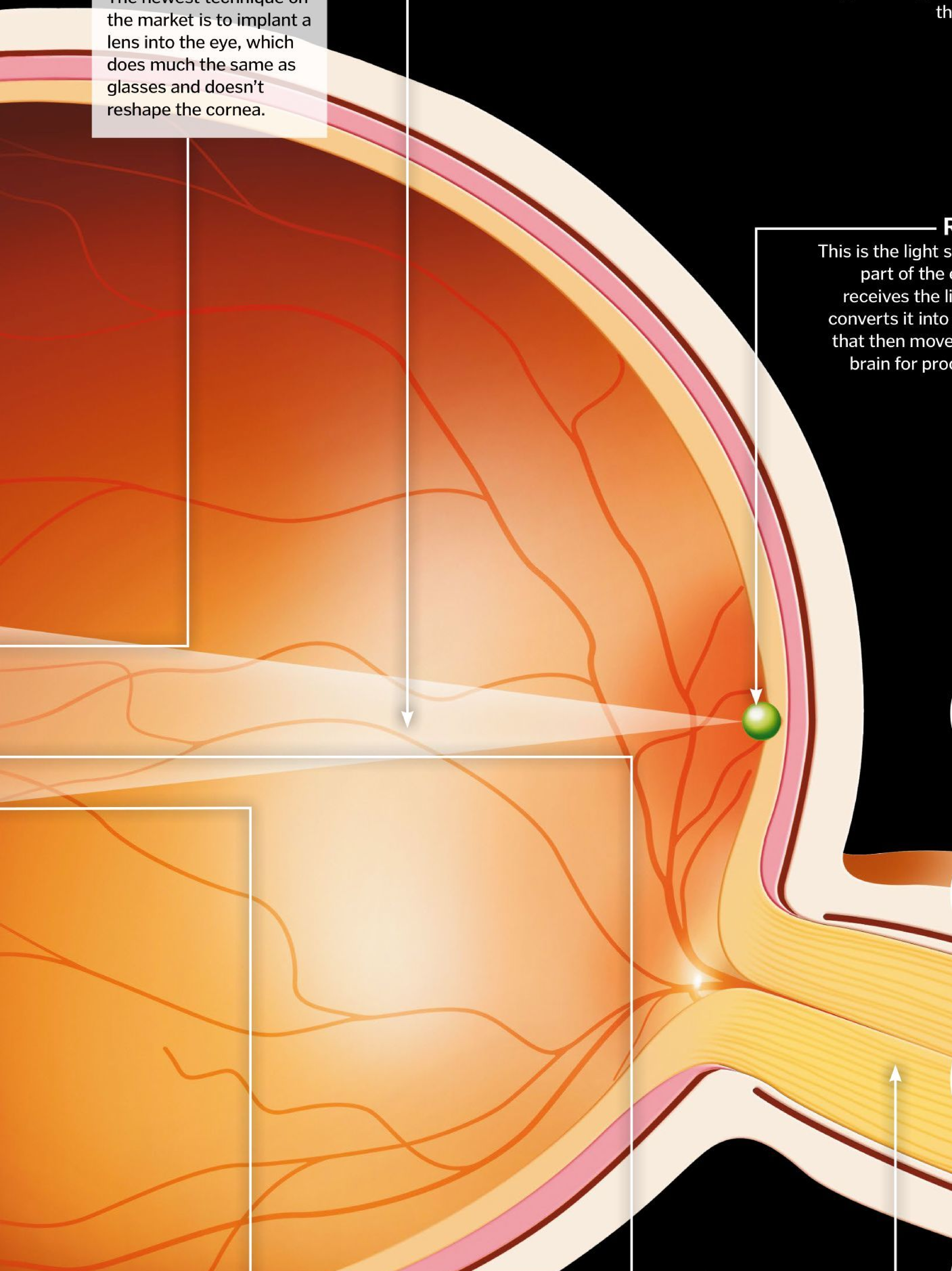
Laser eye surgery is not limited to curing long and short-sightedness. Modern technology is also able to cure astigmatism, which happens when a person's cornea is an irregular shape, which means light doesn't enter the retina cleanly and is bounced about, resulting in blurred vision. The laser is able to reshape the cornea.

The cornea in a short-sighted eye is bent too much, so when light enters, the image gets formed too early and becomes blurry when things are far away. The opposite applies to long-sightedness, as the cornea isn't bent enough and the image hasn't been formed by the time it hits the retina.



Laser eye surgery has taken giant leaps forward in the last two decades

DID YOU KNOW? *Eye surgeons are called ophthalmologists, which is Greek for 'study of eyes'*



Intraocular lens
The newest technique on the market is to implant a lens into the eye, which does much the same as glasses and doesn't reshape the cornea.

Short-sightedness
Short-sighted people can see near objects because they are bigger and more light manages to reach the retina.

Retina
This is the light sensitive part of the eye that receives the light and converts it into a signal that then moves to the brain for processing.

The cornea
The very front of the eye is curved in order to bend light towards the retina. If this is too curved, light is overly bent and doesn't reach the retina.

Lens
The lens is also responsible for bending light. As it travels through, it will hit the curved lens of the eye and continue bending. This is not involved in laser eye surgery, though.

Optic nerve
Once light has hit the retina, it will send the signal via the optic nerve at the back of the eye to the brain. It is made up of around a million fibres.

An eye for numbers

We've all heard about 20/20 vision, but what exactly does that mean? Well, eye specialists have worked out how tall letters have to be for a normal eye to be able to see them at 20 feet (6.1 metres). Someone with 20/20 vision can see letters of that height from 20 feet, meaning their vision is just as expected. Someone with 20/40 vision can see something at 20 feet that a person with normal vision can see at 40 feet (12.2 metres). So, the bigger the second number, the worse the vision.

Scale of sight

20/2

VISION OF A FALCON, OVER EIGHT TIMES BETTER THAN A HUMAN

20/20

NORMAL VISION – MINIMUM REQUIREMENT TO BE A FIGHTER PILOT

20/40

WORST YOUR EYES CAN BE AND STILL BE ALLOWED TO DRIVE

20/80

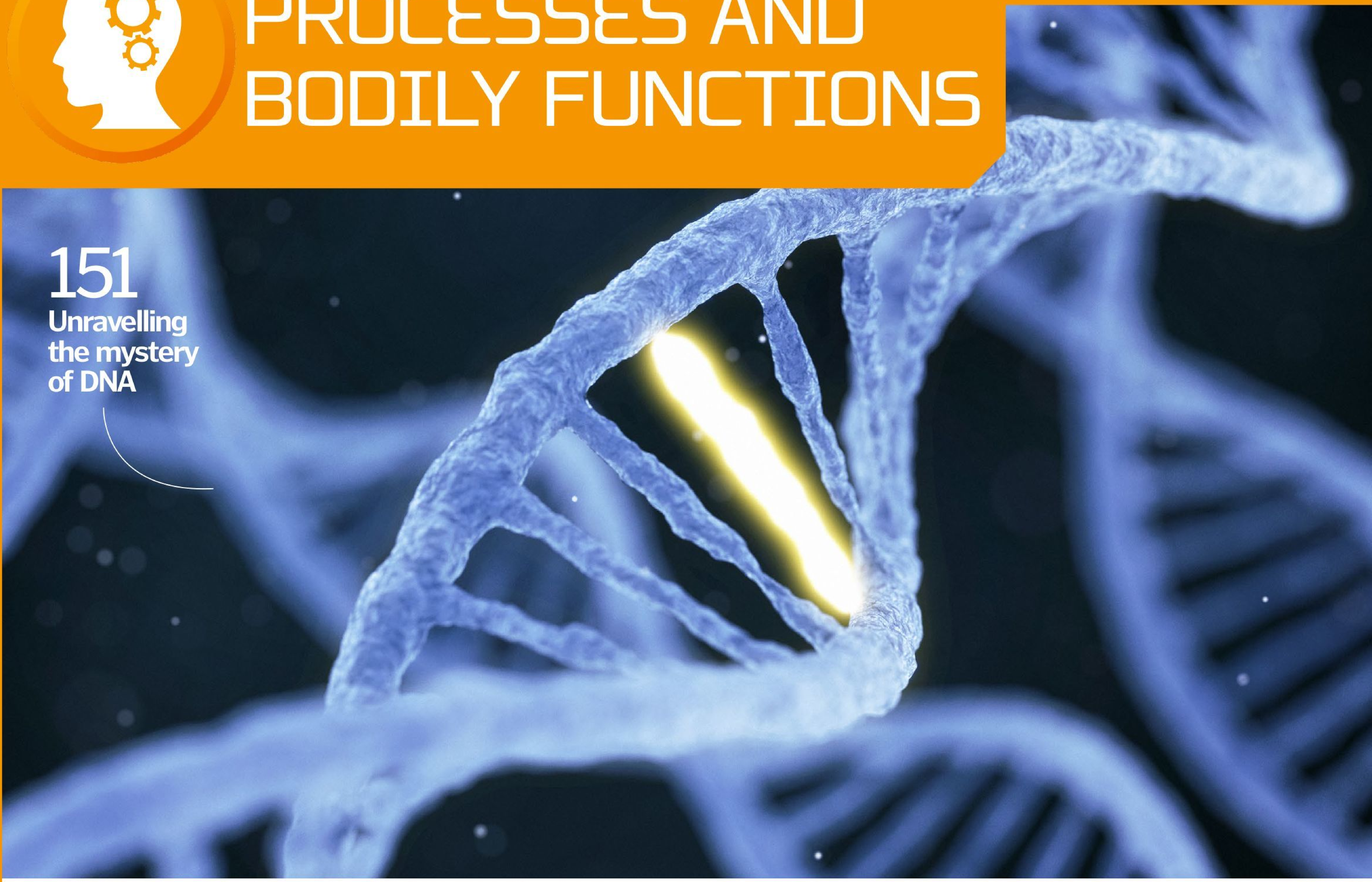
STILL JUST ABOUT ABLE TO READ NEWSPAPER HEADLINES

20/200

LEGALLY BLIND – HOWEVER, YOU STILL CAN SEE STOP SIGNS

© SPL; Getty; Thinkstock

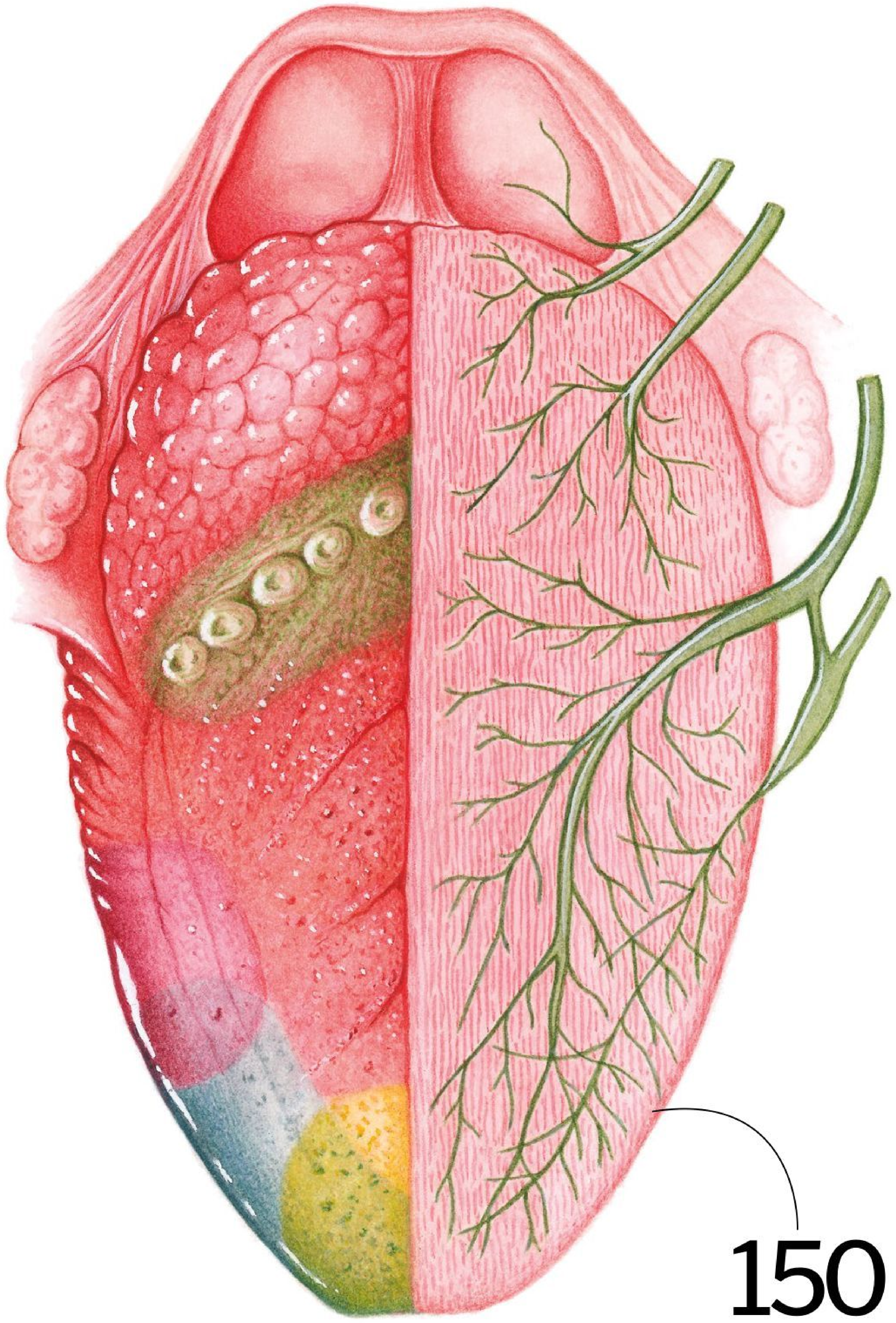
PROCESSES AND BODILY FUNCTIONS



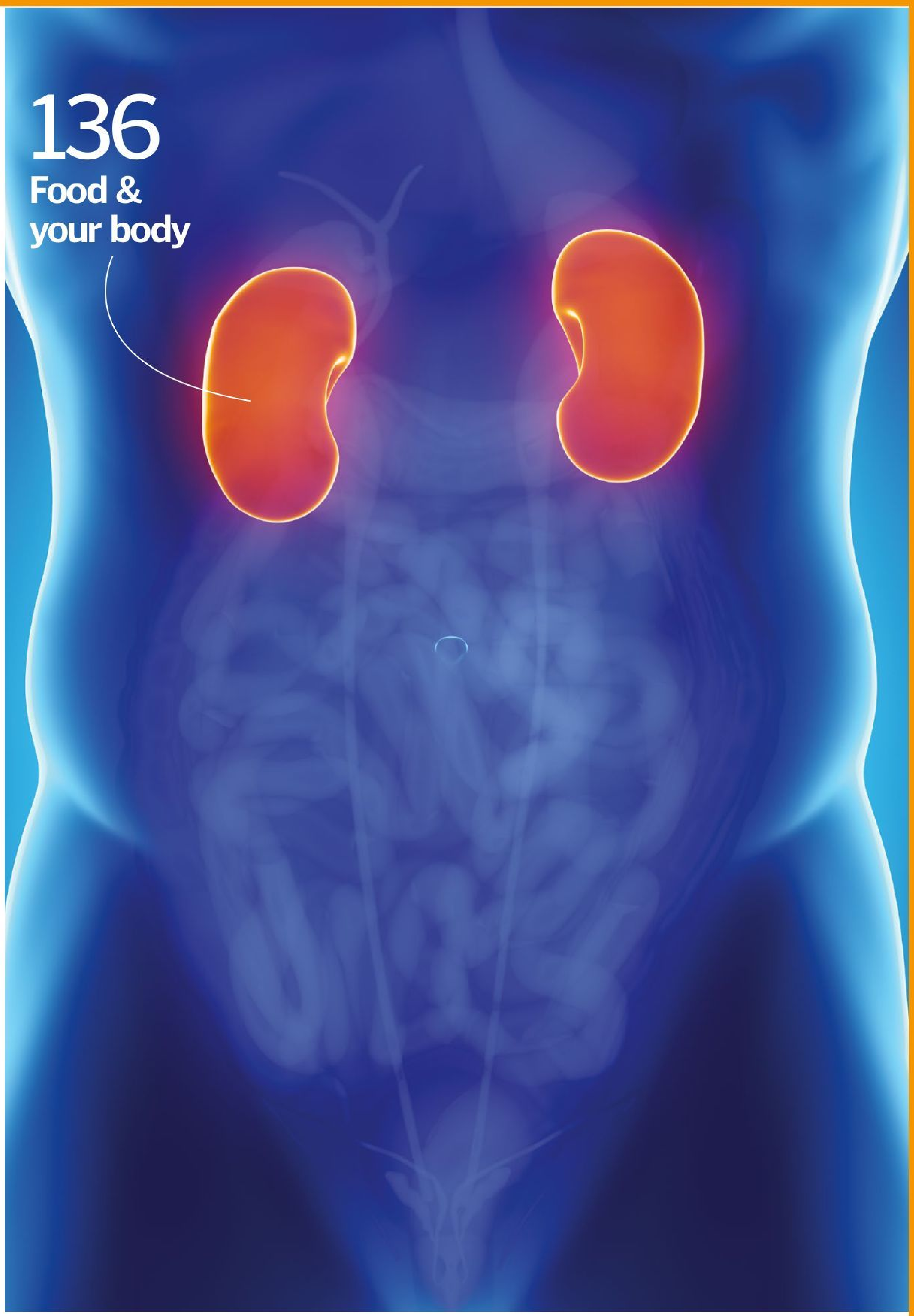
151
Unravelling the mystery of DNA

136 Food & your body
144 The science of happiness
148 The gut-brain axis
150 The five basic human tastes
151 Unravelling the mystery of DNA
152 Correcting heart rhythms
152 Carpal tunnel syndrome
153 What are pheromones?
153 Eczema explained
154 Inside the flu
156 How we swallow
156 Why do we get drunk?
157 The human tongue
157 How do we laugh?
158 What happens when you sneeze?
158 Knee-jerk reactions explained
159 How do we touch and feel?

154
Inside the flu



150
The five basic human tastes



136
Food & your body

How do we touch and feel? 159

144
The science of happiness

FOOD & YOUR BODY

Join us as we unravel all nine metres of your digestive system

The digestive tract is a long, muscular tube that runs the entire length of your body. It is separated into five distinct sections, each with its own particular and specialised function.

Digestion begins in the mouth. As you chew your food, saliva is released, providing a slippery lubricant and kick-starting the break down of carbohydrates with an enzyme known as amylase. Touch receptors in your mouth tell you when it is time to swallow, and as your tongue comes upward, the food is pushed to the back of your throat.

As you swallow, you pass control of digestion over to your automatic motor functions. A flap of skin called the epiglottis folds down to cover the voice box, and the entrance to the lungs, and then a wave pushes the mouthful all the way down the oesophagus. When the food reaches your stomach, it passes through a ring of muscle known as the cardiac sphincter, which prevents it from coming back out the way it came in.

The inside of the stomach is a hostile environment, where the cells lining the walls pump out hydrochloric acid and protein-digesting enzymes. The presence of food triggers stretch receptors in the stomach lining, which in turn trigger a series of rhythmic contractions. These churn the stomach contents, mixing in the acid and enzymes, grinding down the food.

At the bottom of the stomach there is a second ring of muscle called the pyloric sphincter, which acts as a gatekeeper to the small intestine. The sphincter prevents

DID YOU KNOW? *Biological washing powder uses digestive enzymes to break down the stains on dirty laundry*

anything larger than about two centimetres (0.8 inches) in diameter passing through, returning it to the body of the stomach until it has been ground down further. This ensures that by the time it reaches the small intestine, your food is a runny, slightly lumpy paste, and is ready for the next stage of digestion.

The small intestine is the site of chemical digestion. Here, the pancreas adds digestive enzymes, and the liver adds a generous squirt of alkaline bile, delivered via the gall bladder. This bile not only neutralises the burning stomach acid, it also acts a little like washing-up liquid on dirty dinner dishes, helping to separate the food particles and forcing fats to disperse into tiny bubbles.

Muscles in the small intestine continue to squeeze and mix the contents together, allowing the enzymes to get to work inside the paste. As the nutrients are released, they are then absorbed over the walls of the intestine and into the bloodstream.

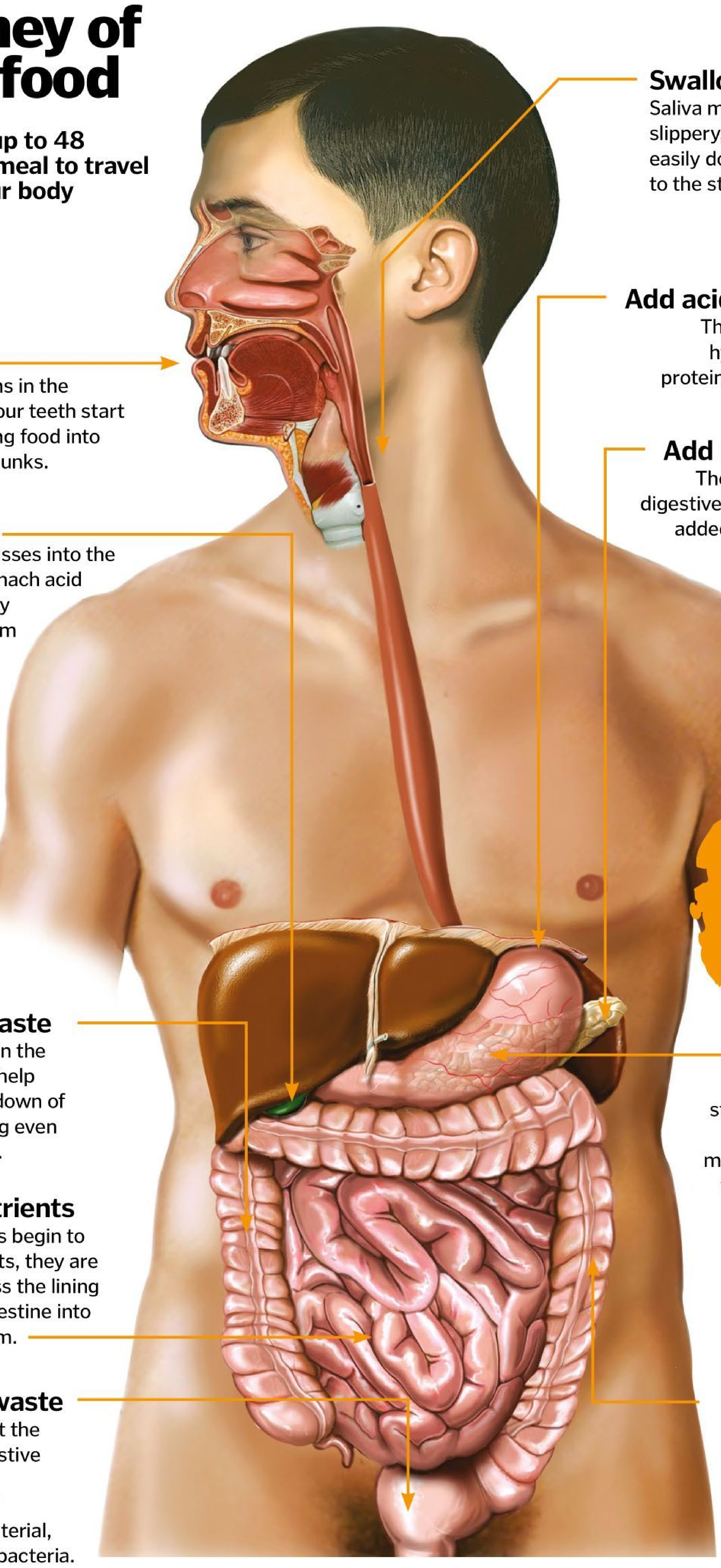
To ensure that everything keeps moving through the system, every five to ten minutes a wave of muscle contractions begins at the stomach and travels all the way down the intestines. Known as the migrating motor complex (MMC), this wave squeezes the digestive system like a tube of toothpaste, urging its contents further toward the colon.

As the food progresses through the system to the small intestine, more and more of the nutrients are released by enzyme activity, and by the time it reaches the large intestine, most of the useful material has been absorbed into the bloodstream. However, the digestive process is not yet over, and here, bacteria help to break down even more of what's left of the undigested food.

The large intestine also absorbs most of the remaining water, leaving behind a combination of undigested material, dead cells and bacteria. When the waste has completed its journey through the large intestine it goes to the rectum for storage until there is a convenient time to get rid of it.

Journey of your food

It can take up to 48 hours for a meal to travel through your body



Swallow
Saliva makes each mouthful slippery, allowing it to slide easily down the oesophagus to the stomach.

Chew
Digestion begins in the mouth, where our teeth start work on grinding food into manageable chunks.

Add acid and enzymes
The stomach produces hydrochloric acid, and protein-digesting enzymes.

Add more enzymes
The pancreas produces digestive enzymes, which are added to the mixture as it enters the small intestine.

Add bile
As the liquid passes into the intestines, stomach acid is neutralised by alkaline bile from the liver.

7 *metres*
LENGTH OF THE SMALL INTESTINE

Ferment waste
Bacteria living in the large intestine help with the breakdown of waste, releasing even more nutrients.

Churn
The muscles of the stomach rhythmically churn its contents, mechanically breaking the food down into a lumpy paste.

Absorb nutrients
As the enzymes begin to release nutrients, they are absorbed across the lining of the small intestine into the bloodstream.

Get rid of waste
All that is left at the end of the digestive process is a combination of indigestible material, dead cells and bacteria.

Remove water
The large intestine absorbs excess water from the food as it passes through.

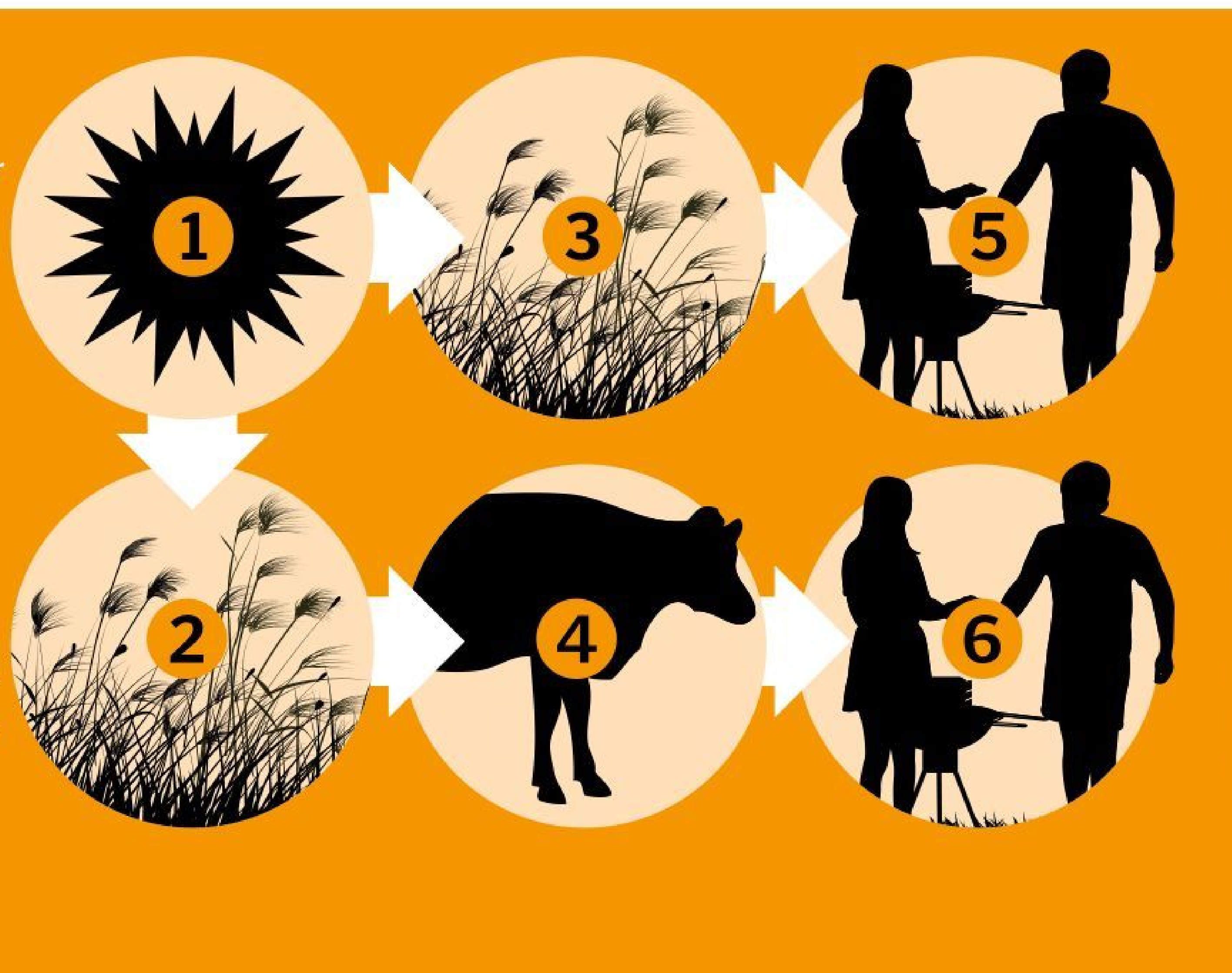
Food chain

Energy from the Sun is converted into chemical energy by photosynthetic organisms like plants. The plants use the energy to build biological materials from nutrients in the air and soil. Herbivores then consume the plants, releasing some of the energy, and using the components to build their own bodies. Carnivores then eat the herbivores. When plants and animals die, decomposers break their bodies down, returning nutrients to the ground for reuse, and the cycle begins again.

1 The Sun
On average, every minute the Sun delivers 2kcal of energy for every cm^2 (0.2in^2) of Earth.

2 Inefficient conversion
Less than five per cent of the available energy from the Sun is converted into chemical energy by plants.

3 Producer
Plants use the energy from the Sun to combine CO^2 and water, producing chemical energy in the form of sugars.



4 Herbivore
Herbivores can digest plant material, but the process is difficult, and they can only extract around ten per cent of the energy.

5 Energy loss
At every step up in the food chain, some of the energy is lost, mostly as heat.

6 Carnivore
Carnivores get easy energy by digesting the tissues of other animals.

Sense of taste

Taste tells us whether our food is safe to eat, but smell gives it flavour

The human tongue is able to detect five different tastes: sweet, sour, salty, bitter and umami (savoury), providing us with a quick way to distinguish between different types of food. Sweet foods contain sugar and are a good source of energy. Salty foods provide sodium, which is vital for nerve function, but deadly in high quantities. Bitter foods might contain poison.

Babies are born with a natural preference for sweet food and a dislike of bitter, providing a biological safeguard that encourages them to eat safe, high-calorie food. However, nutrition is not that simple. Many vegetables are bitter but not poisonous and so learning to like them comes with experience.

The degree to which we can detect different tastes varies, and appears to be dictated by our individual anatomy. The population can be broadly divided into three categories based on the number of taste buds on their tongue. Those with the fewest are known as 'non-tasters', those with an average number are known as 'tasters', and those with many more taste buds than the rest of the population are 'supertasters.' Supertasters are especially sensitive to taste and will react much more strongly than the rest of the population. As a result, they tend to really dislike bitter foods like green vegetables and coffee, and often shy away from rich desserts and sugary sweets.

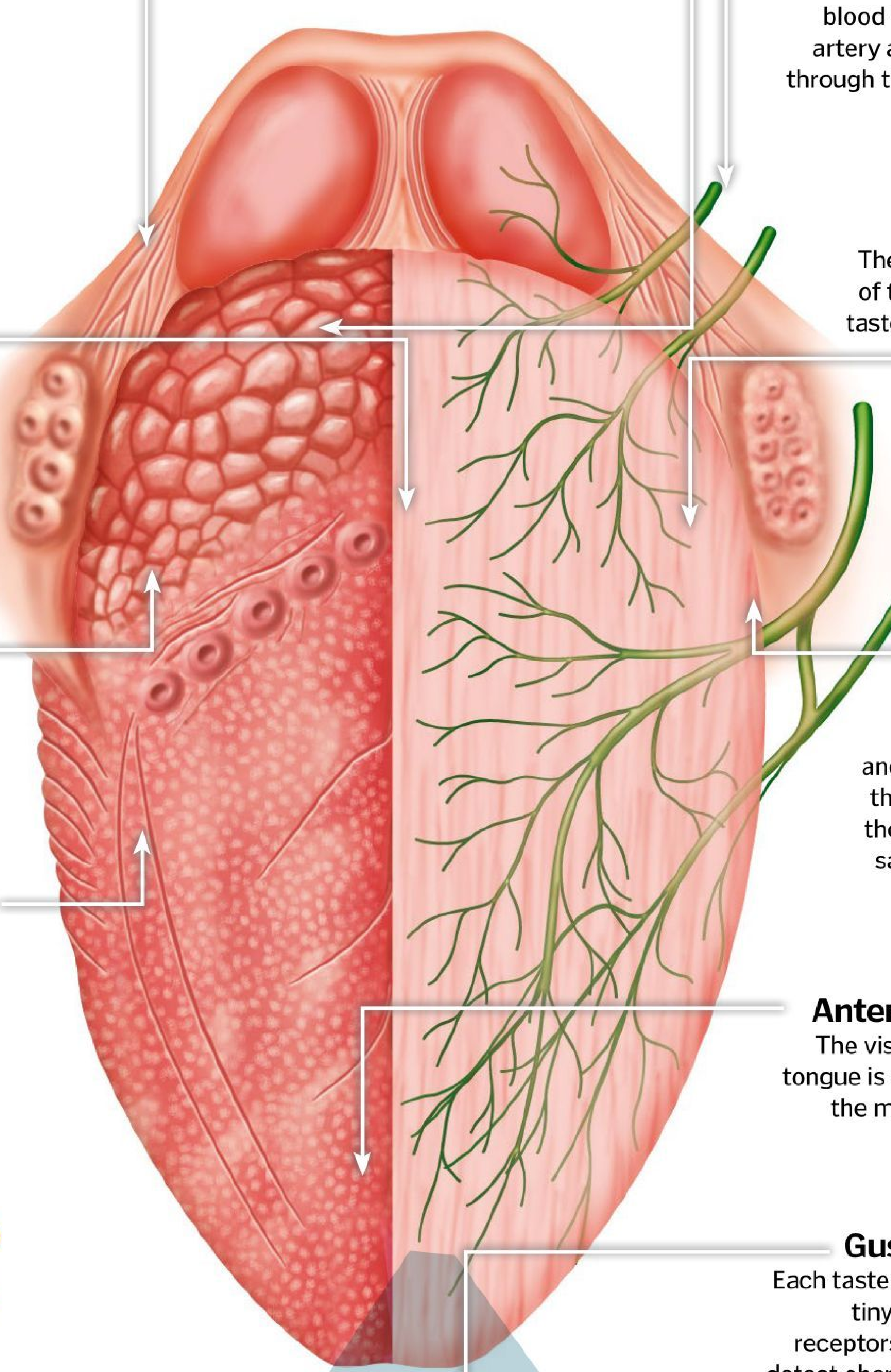
Though these anatomical differences can explain some of our food preferences, most of our individual likes and dislikes are not down to taste, but to flavour; the combination of taste and smell.

The act of chewing food releases chemicals known as volatiles, which evaporate rapidly. As we swallow, some of the air inside the mouth is forced up toward the nose, carrying these volatiles with it. Here, they bind to receptors on olfactory cells, triggering sensory messages to the brain.

Recently, scientists have found that these olfactory receptors can detect as many as 1 trillion different odours. Taste and smell are strongly linked to emotion and memory, and as a result, experience is a powerful decider in the development of our likes and dislikes.

Anatomy of a human tongue

Contrary to popular belief, all five tastes can be detected almost anywhere on the tongue



Muscle
There are eight muscles in the tongue that alter its shape and change its position.

Posterior tongue
About a third of the tongue is hidden right at the back of the mouth.

Papillae
The tongue is covered in tiny bumps, but not all of them contain taste buds.

Filiform papillae
Most of the tongue is covered in thin, rough bumps that contain no taste receptors.

Circumvallate papillae
These large bumps are found at the back of the tongue, each surrounded by a dip that collects saliva.

Blood supply
The tongue receives blood from the lingual artery and it drains out through the lingual veins.

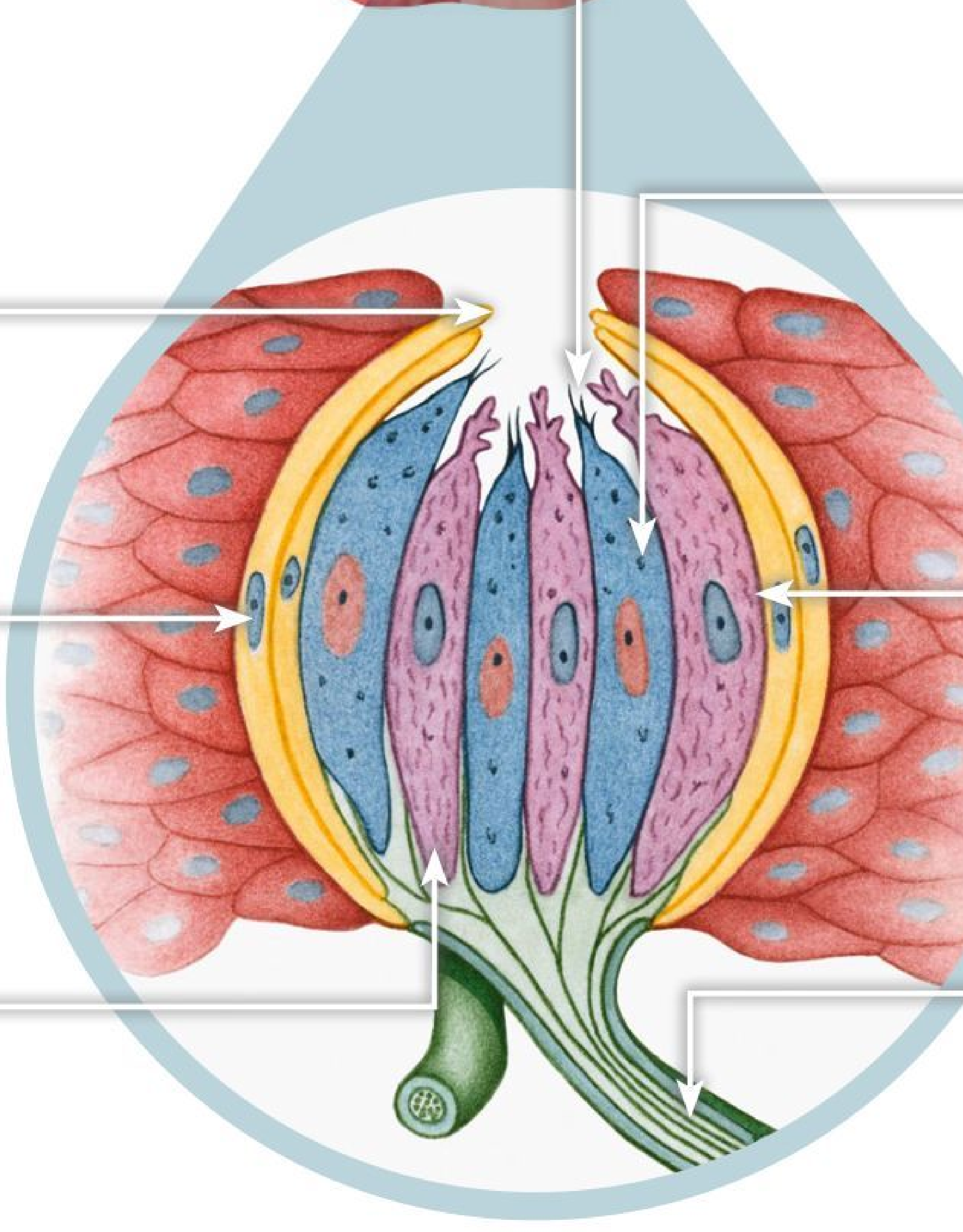
Nerves
The front and back of the tongue send taste information to the brain.

Foliate papillae
These contain taste receptors and are located on the back edges of the tongue, where saliva drips down the cheeks.

Anterior tongue
The visible part of the tongue is responsible for the majority of taste detection.

10
TASTE CELLS ARE REPLACED EVERY TEN DAYS

What is a taste bud?



Pore
A tiny gap at the top of the taste bud allows saliva to touch the taste cells.

Support cell
The taste cells are surrounded by an envelope of non-tasting support cells.

Synapse
Taste cells do not transmit the signals to the brain themselves, instead passing the message over to a nerve cell.

Gustatory hair
Each taste cell ends with a tiny hair, covered in receptors that allow it to detect chemicals dissolved in the saliva.

Basal cell
Ageing or damaged taste cells are replaced by the basal cells waiting underneath.

Sensory cell
Each cell is sensitive to one of the five tastes, but all types are found together in a single taste bud.

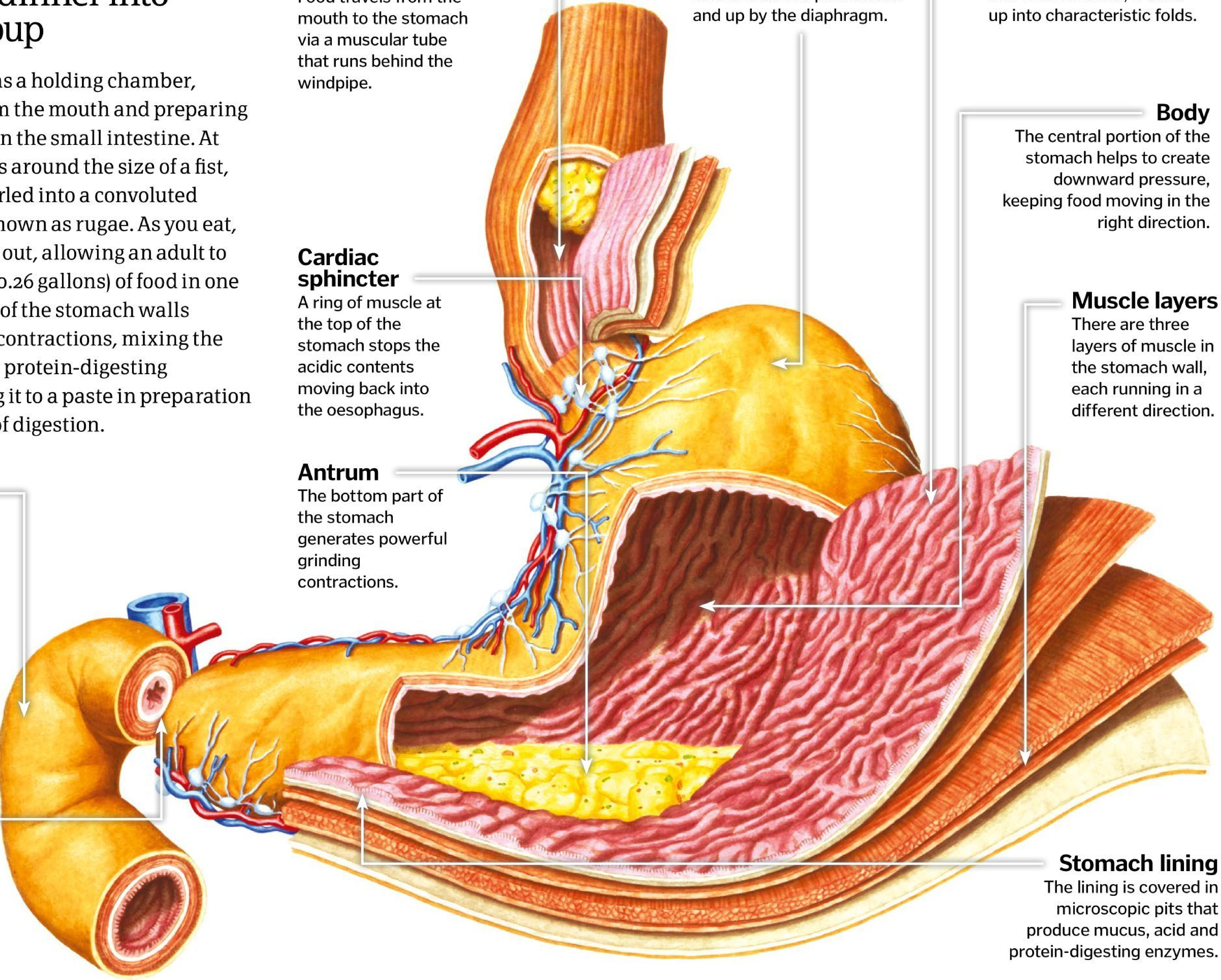
Nerve
Messages are relayed to the brain via a nerve that exits at the bottom of the taste bud.

DID YOU KNOW? *Stomach ulcers were long thought to be caused by stress, but it's now known the culprit is a bacterial infection*

Inside the stomach

This muscular bag turns your dinner into an acidic soup

The stomach acts as a holding chamber, receiving food from the mouth and preparing it to be processed in the small intestine. At rest, the stomach is around the size of a fist, and its lining is curled into a convoluted network of folds known as rugae. As you eat, these folds stretch out, allowing an adult to eat around a litre (0.26 gallons) of food in one sitting. Stretching of the stomach walls triggers rhythmic contractions, mixing the food with acid and protein-digesting enzymes, grinding it to a paste in preparation for the next stage of digestion.



Oesophagus
Food travels from the mouth to the stomach via a muscular tube that runs behind the windpipe.

Fundus
Excess gas is collected at the top of the stomach, where it can be pushed out and up by the diaphragm.

Rugae
The lining of the stomach is stretchy and expandable, and when relaxed, it curls up into characteristic folds.

Body
The central portion of the stomach helps to create downward pressure, keeping food moving in the right direction.

Cardiac sphincter
A ring of muscle at the top of the stomach stops the acidic contents moving back into the oesophagus.

Muscle layers
There are three layers of muscle in the stomach wall, each running in a different direction.

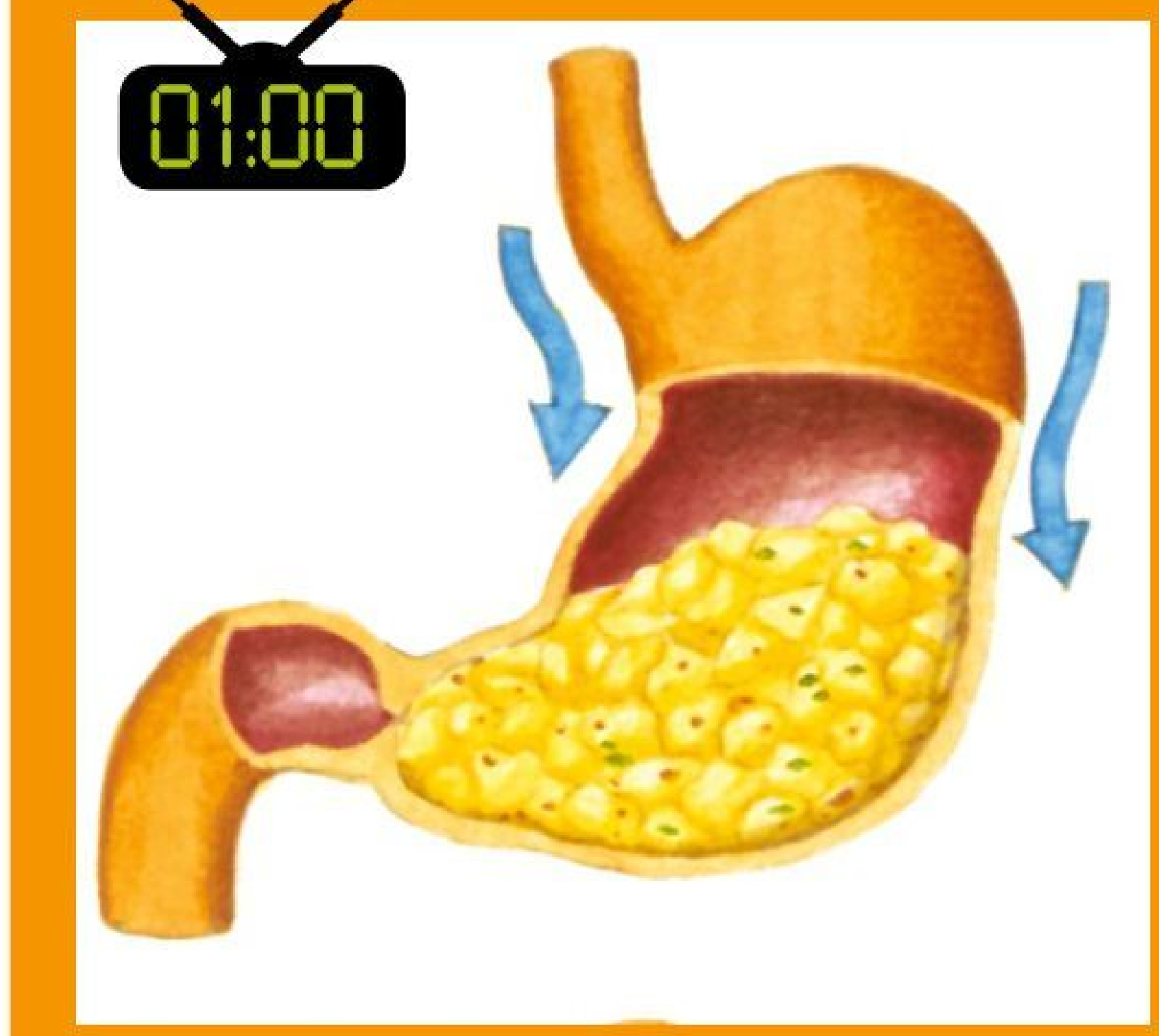
Antrum
The bottom part of the stomach generates powerful grinding contractions.

Duodenum
The stomach empties its contents into the first section of the small intestine.

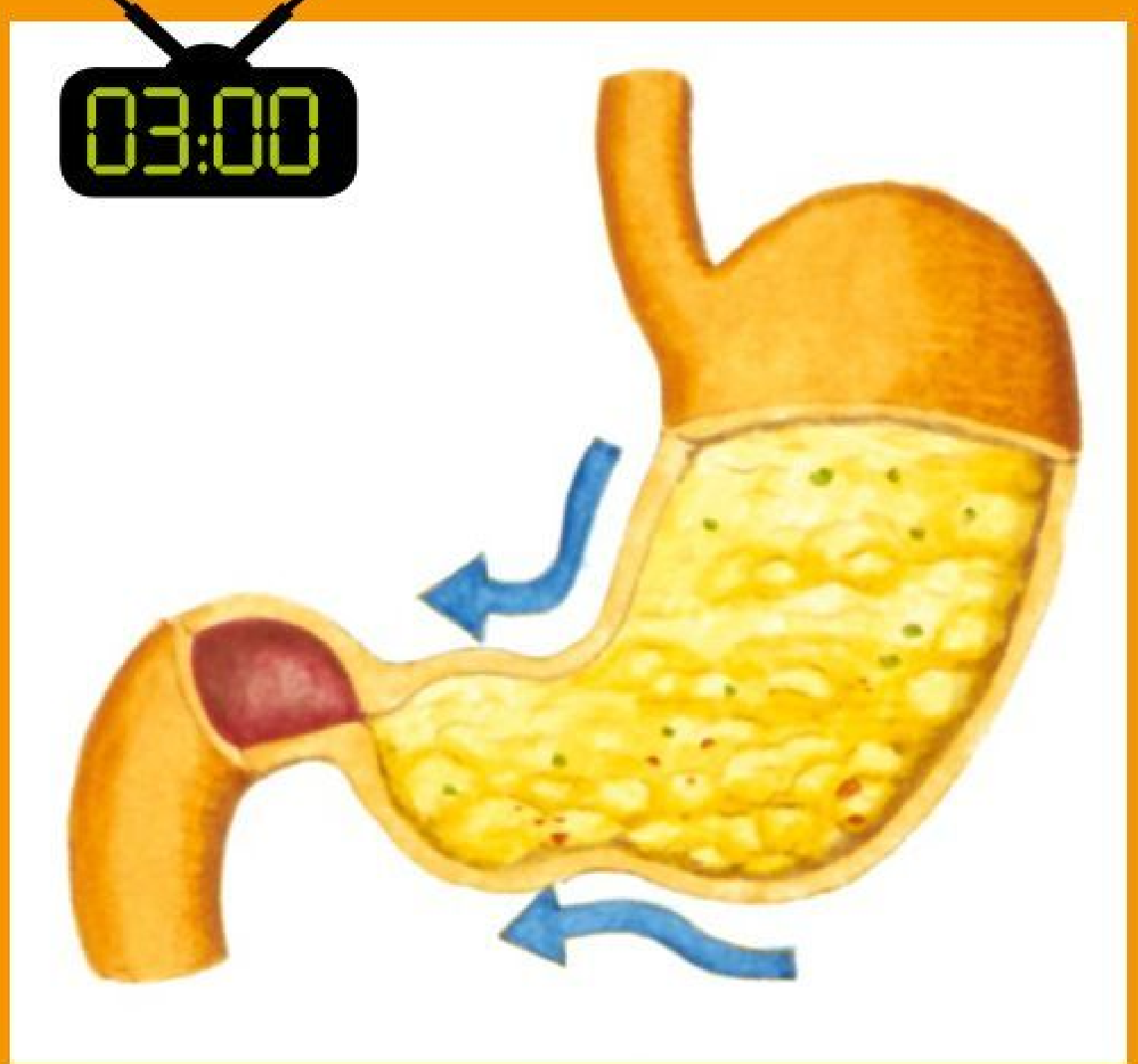
Pyloric sphincter
A ring of muscle at the base of the stomach prevents the contents from leaking out before they are ready.

Stomach lining
The lining is covered in microscopic pits that produce mucus, acid and protein-digesting enzymes.

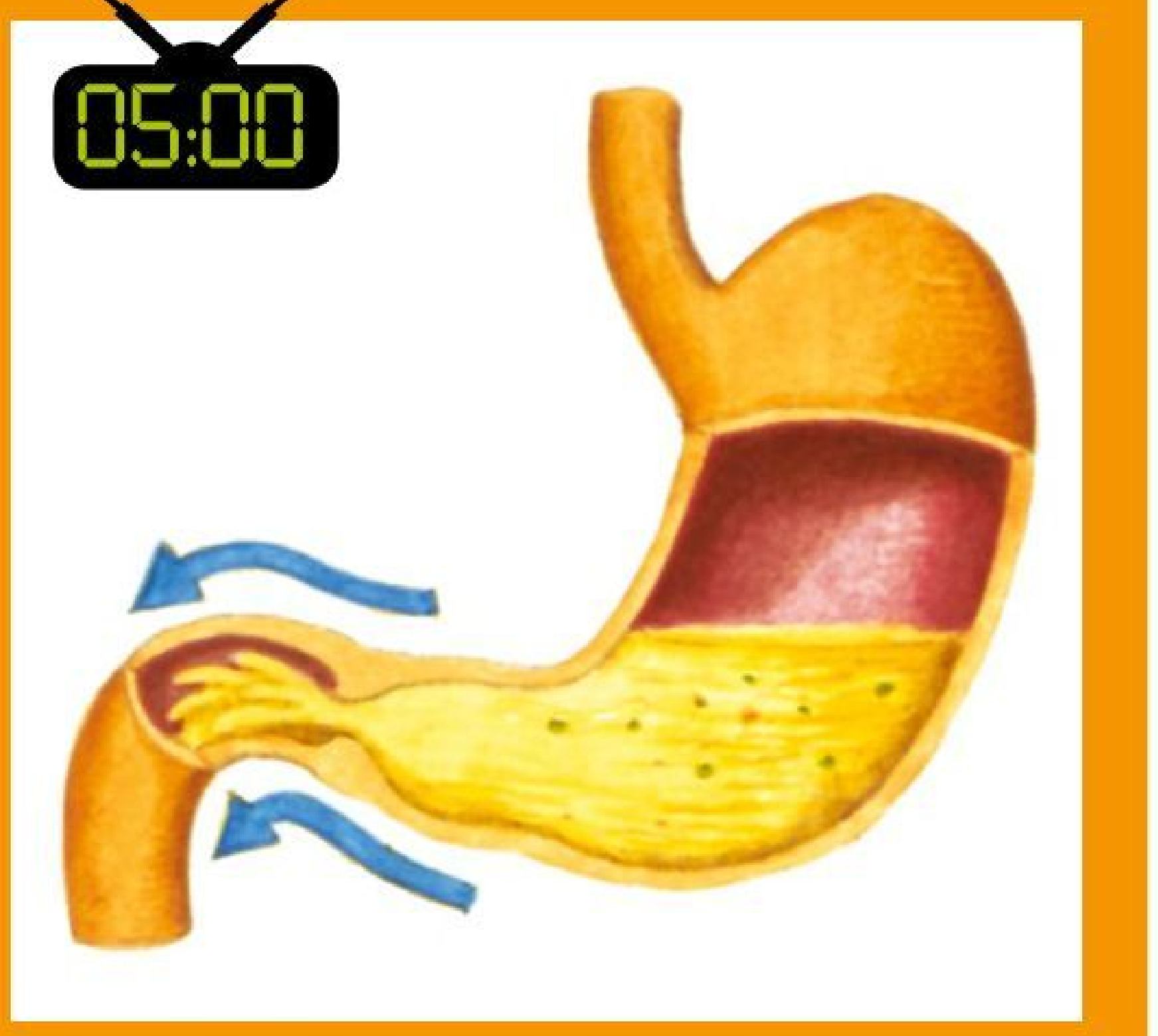
How long does it take to digest food?



The sight, smell and even the thought of food begin to prepare the stomach for a meal, so by the time the swallowed mouthfuls start to arrive, it is already producing more acid.



Stretching and irritation of the stomach trigger it to turn up acid and enzyme production and to start churning. For the first 20 to 30 minutes after eating a meal, no food is allowed to leave.



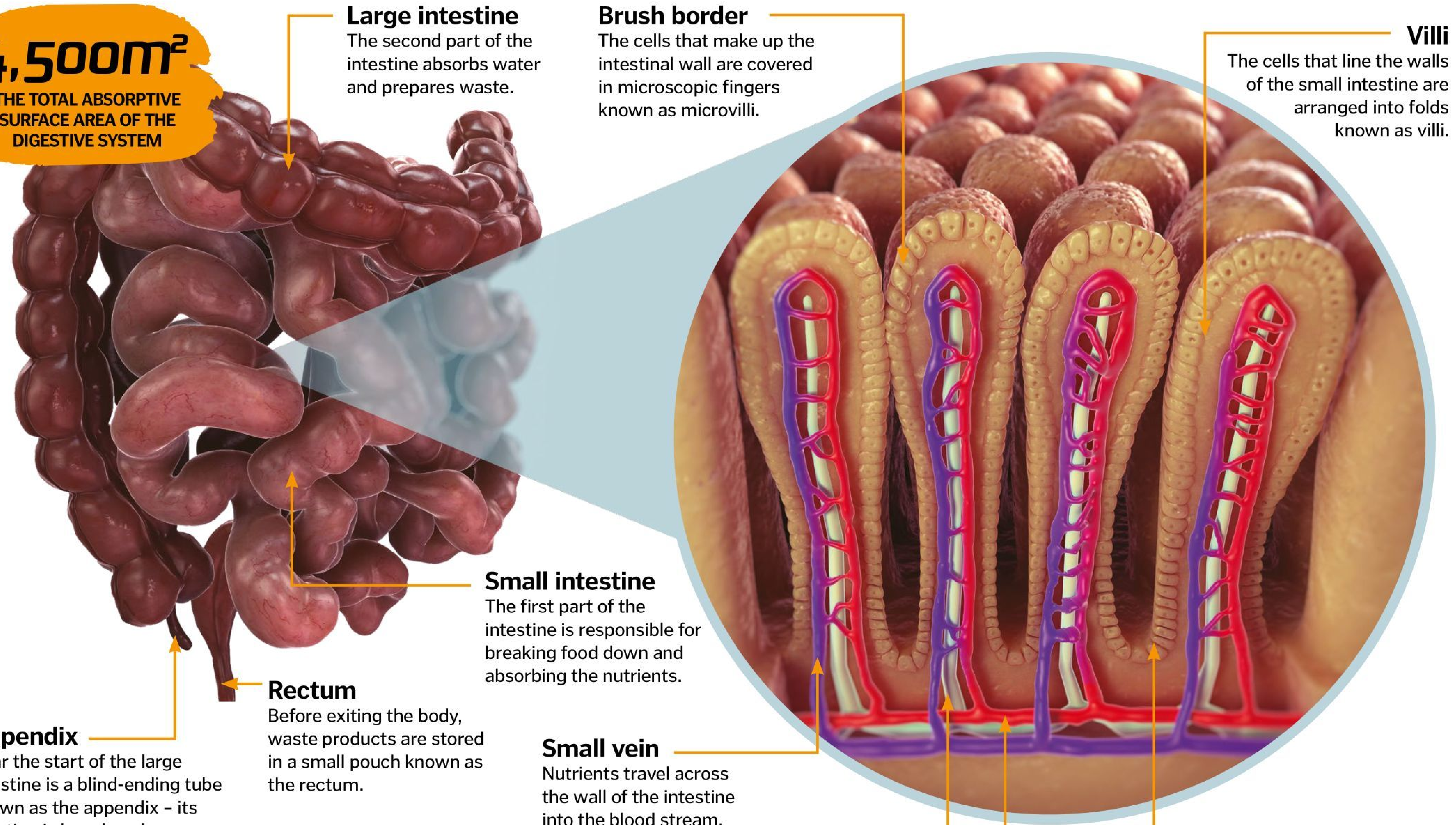
To stop the stomach emptying too quickly, protein and fat are monitored in the first part of the small intestine. If too much food comes through, the intestine sends signals to slow the stomach down.

Chewing the fat

Fat has a bad reputation, but the truth is, your body needs it

Every single cell in your body is surrounded by a membrane made of fats; it insulates your nerves and it provides a valuable energy reserve. Eating fat also provides a number of vitamins and essential fatty acids the body can't make on its own. Saturated fats (the solid fats found in meat and dairy) and trans fats (found in hydrogenated vegetable oil and many processed foods) have shown to raise cholesterol, which can lead to circulatory problems, but unsaturated fats (the liquid fats found in plants and fish) can have the opposite effect, and are considered good for your health.

$4,500\text{m}^2$
THE TOTAL ABSORPTIVE SURFACE AREA OF THE DIGESTIVE SYSTEM



Large intestine The second part of the intestine absorbs water and prepares waste.

Brush border The cells that make up the intestinal wall are covered in microscopic fingers known as microvilli.

Villi The cells that line the walls of the small intestine are arranged into folds known as villi.

Small intestine The first part of the intestine is responsible for breaking food down and absorbing the nutrients.

Rectum Before exiting the body, waste products are stored in a small pouch known as the rectum.

Appendix Near the start of the large intestine is a blind-ending tube known as the appendix – its function is largely unknown.

Small vein Nutrients travel across the wall of the intestine into the blood stream.

Lymph vessel Fatty acids are transported away from the intestines via the lymphatic system.

Small artery Each of the villi has a rich blood supply.

Intestinal crypt Between the villi are crypts containing mucus-producing cells.

The intestines

After leaving the stomach, food must pass through over 7m (23ft) of intestines

The stomach contents enter the intestine gradually, allowing time for the liquid food to be processed. First the acid is neutralised by bile, provided by the liver, and then digestive enzymes are added by the pancreas. The enzymes act like molecular scissors, breaking proteins, carbohydrates and fats down into building blocks small enough to be carried over the wall of the small intestine. The remaining undigested material passes into the large intestine, which absorbs water, leaving behind solid waste that can then be passed out of the body.

Living with bacteria

Bacteria are often portrayed as the 'bad guys' of the body, but the proportion that cause food poisoning is surprisingly small. In fact, bacteria start to move into your digestive system from the moment you are born, and a healthy adult has around 300 to 500 different resident species living in their large intestine at any one time.

The upper parts of the digestive system are hostile to microorganisms; the stomach is highly acidic and the small intestine is filled with digestive enzymes, but the large intestine provides the perfect environment for sustaining a microscopic world.

By the time food reaches this point, our digestive enzymes have done their work and most of the nutrients have been absorbed, but bacteria have a different set of enzymes. They are able to break indigestible material down even further, allowing us to absorb even more nutrients, mainly in the form of fatty acids.

The presence of these helpful bacteria also means there is little space or resources left for dangerous pathogens, helping to keep infections at bay.

The gut and its resident bacteria are in constant communication, picking up on chemical signals released into the environment. These signals can have far-reaching effects, and the types of bacteria present in your intestines have been shown to influence other organs, including the brain.

DID YOU KNOW? *The human mouth produces 1-2 litres of saliva every day*

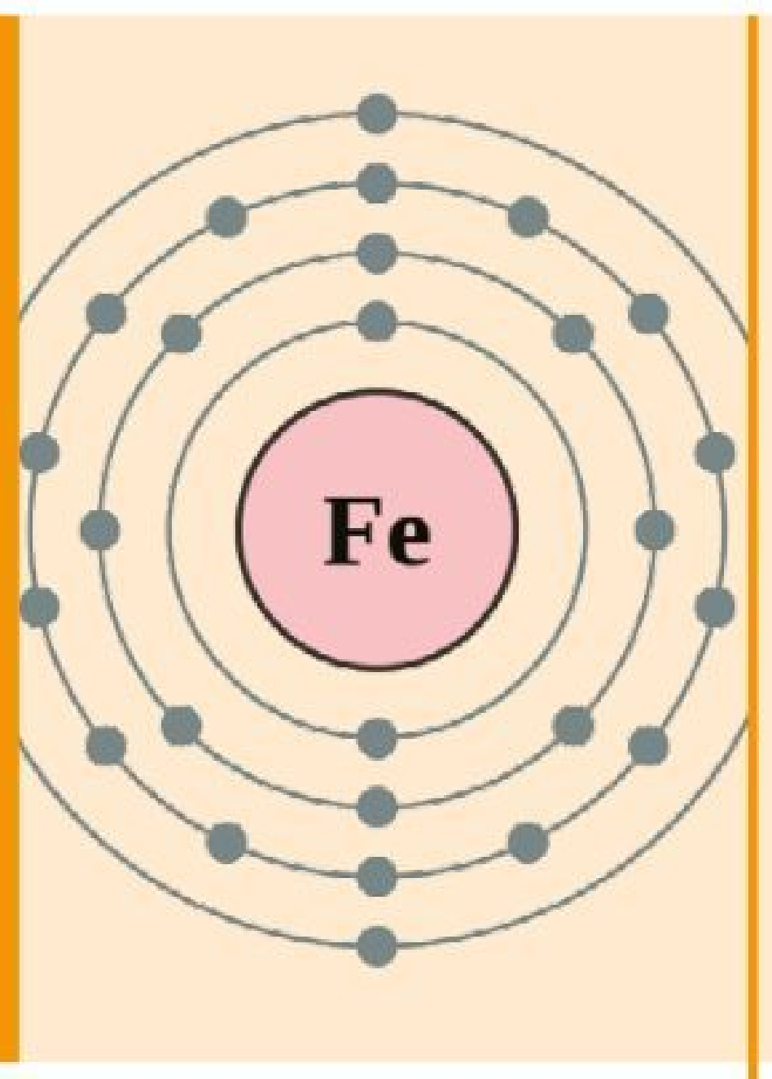
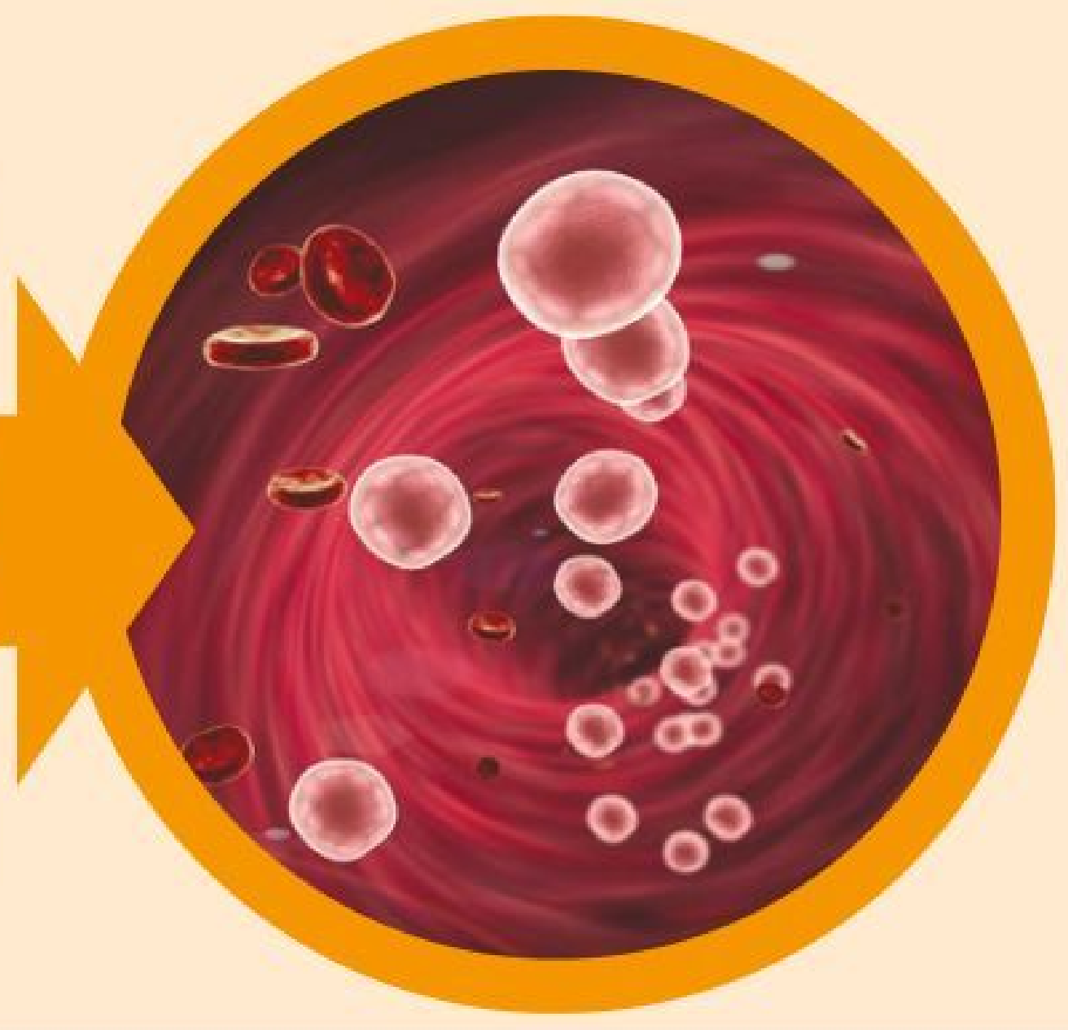
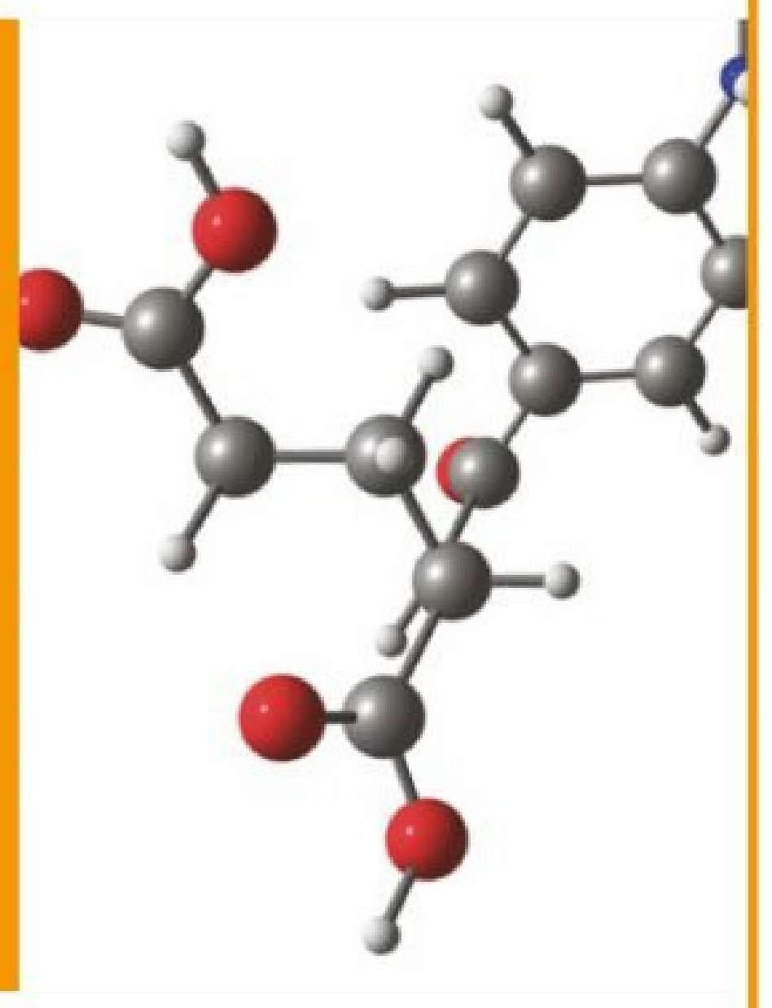
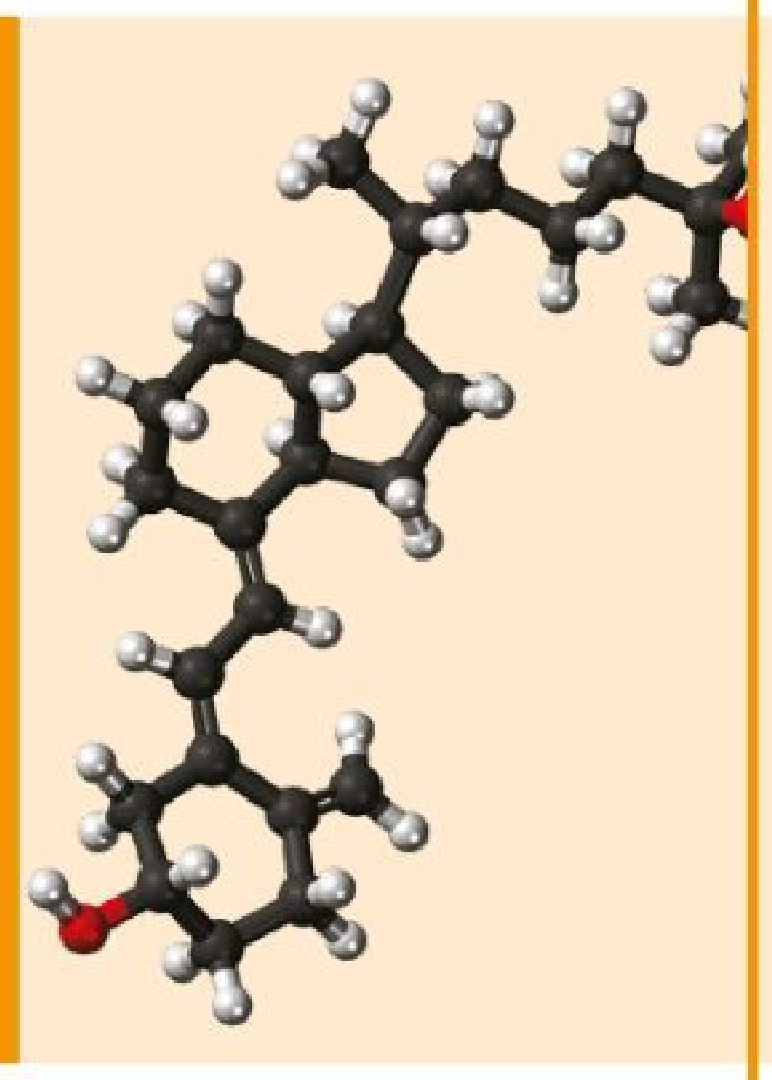
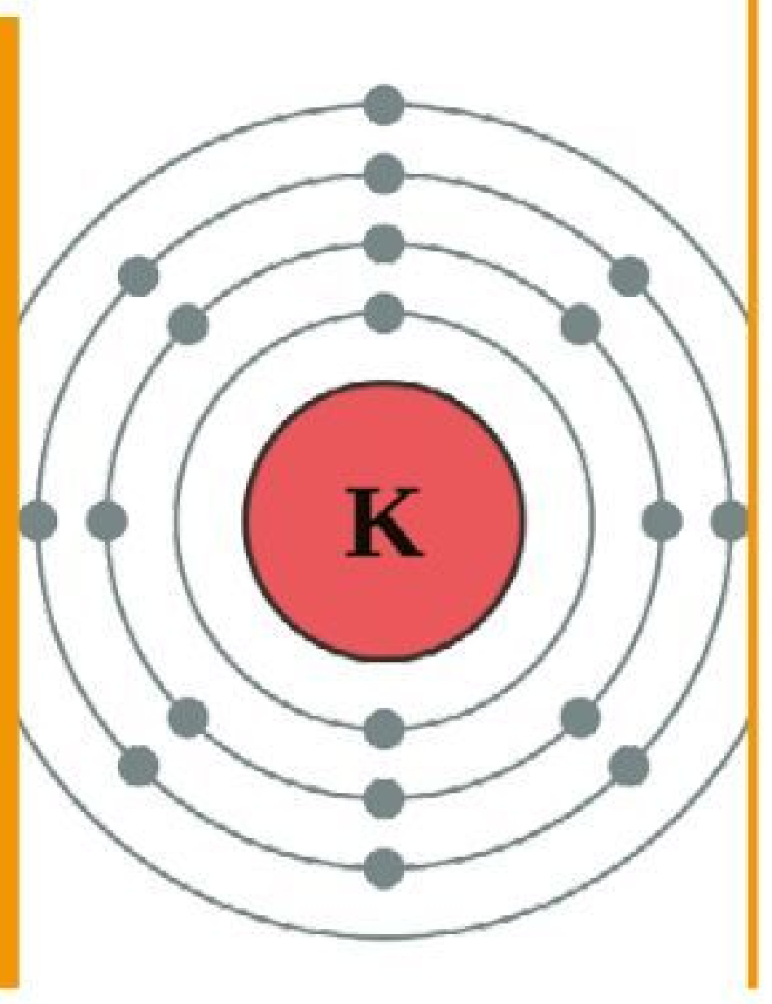
The first part of the digestive system prepares the food for the next stage, ensuring it is broken into a fine paste, mixed to form a homogenous fluid, and shocked with acid to limit the potential for dangerous infection. However, it is not until food reaches the small intestine that the microscopic breakdown and absorption of nutrients really begins.

At the start of the small intestine, the liver injects alkaline bile into the acidic liquid food, neutralising its pH and preparing it for the introduction of digestive enzymes.

Bile also helps to emulsify fats. Fats are not water soluble, so they tend to clump together in large globules to hide from and avoid the surrounding water, but bile acts a little like washing-up liquid, separating the fats out into smaller blobs.

Now that the food is nicely mixed and separated, the enzymes can get to work. The pancreas produces a cocktail of three kinds of enzyme, each used to break down a different type of molecule. Proteases clip amino acids from proteins, lipases break fats down into fatty acids and glycerol, and carbohydrases turn long chains of carbohydrate into sugars. These small blocks can be absorbed into the bloodstream, where they're distributed around the body, used to build our own biological molecules, or broken down and burnt for energy. The body requires different quantities of each of the nutrients, and can sometimes convert one into another if supplies are running low. However, there are a number of nutrients that cannot be synthesised by the body at all or in high enough quantities, and these must be obtained directly from the diet. These essential nutrients include some types of amino acids, fatty acids like omega-3 and omega-6, and all of the vitamins and minerals needed.

Vitamins and minerals are organic and inorganic compounds required by the body in small amounts for various different functions. Some of these, like calcium, make up vital structural components of our bodies, while others, like vitamin C, are involved in biochemical reactions.

MOLECULE / VITAMIN	FOOD YOU'LL FIND IT IN	WHAT THE BODY USES IT FOR
IRON  	**IRON-RICH FOOD** Egg yolks Red meat Spinach	 Iron is a key component of haemoglobin, the red pigment that carries oxygen in our blood. Without it, oxygen cannot be transported effectively, resulting in iron-deficiency anaemia. This is most often caused by blood loss, so as a result, women are much more likely to be deficient of iron than men.
FOLIC ACID 	**GREEN LEAFY VEGETABLES** Cauliflower Broccoli Brussels sprouts	 Folic acid is essential for the synthesis of DNA and without it the production of red blood cells starts to slow down. It is also extremely important in the formation of the central nervous system, and during the first 12 weeks of pregnancy, folic acid supplementation is recommended to pregnant women.
VITAMIN D 	**OILY FISH** Salmon Tuna Caviar	 Vitamin D is involved in bone formation in the body, so deficiency of vitamin D in children can result in bone deformity. Luckily, this vitamin is easy to obtain. Not only can vitamin D be found in oily fish, eggs and dairy products, but our bodies can also make it themselves using sunlight.
POTASSIUM  	**FRUITS** Dried apricots Avocados Bananas	 Cells use a combination of potassium and sodium to maintain their internal electrical balance. Potassium is vital to ensure muscles are able to contract properly and nerves are able to transmit their messages. It is easily obtained in the diet and deficiency is incredibly rare unless there is damage to the kidneys.

Food and the brain

Why do we crave these foods?

Hunger is one of the body's most basic and fundamental sensations, and it originates in the stomach. When the stomach is empty, it begins to produce a hormone known as ghrelin. This then travels to a region of the brain known as the hypothalamus.

The hypothalamus is responsible for maintaining a constant, optimum state; keeping the body at a set temperature, regulating hormones and monitoring hydration. The arrival of ghrelin is a signal that energy levels might be about to dip, so it triggers the production of a second hormone, neuropeptide Y. This hormone promotes eating.

The cue to stop eating is much more subtle. The stomach has stretch receptors, and will signal to the brain that it is full. But what happens if the stomach is empty, but there is already enough energy stored in the system? Fat stores produce a hormone known as leptin, which tells the brain exactly how much energy the body has in reserve. When leptin levels are high, the hypothalamus makes hormones that suppress appetite. The trouble is that with high levels of fat, we can become resistant to the leptin message, similar to insulin resistance in type-II diabetes. If the brain does not know there is enough fat, we just keep eating.

Cravings are slightly different. These are generated not in the stomach, but in the brain. There are three main areas of the brain implicated in food cravings, the hippocampus, the insula and the caudate.

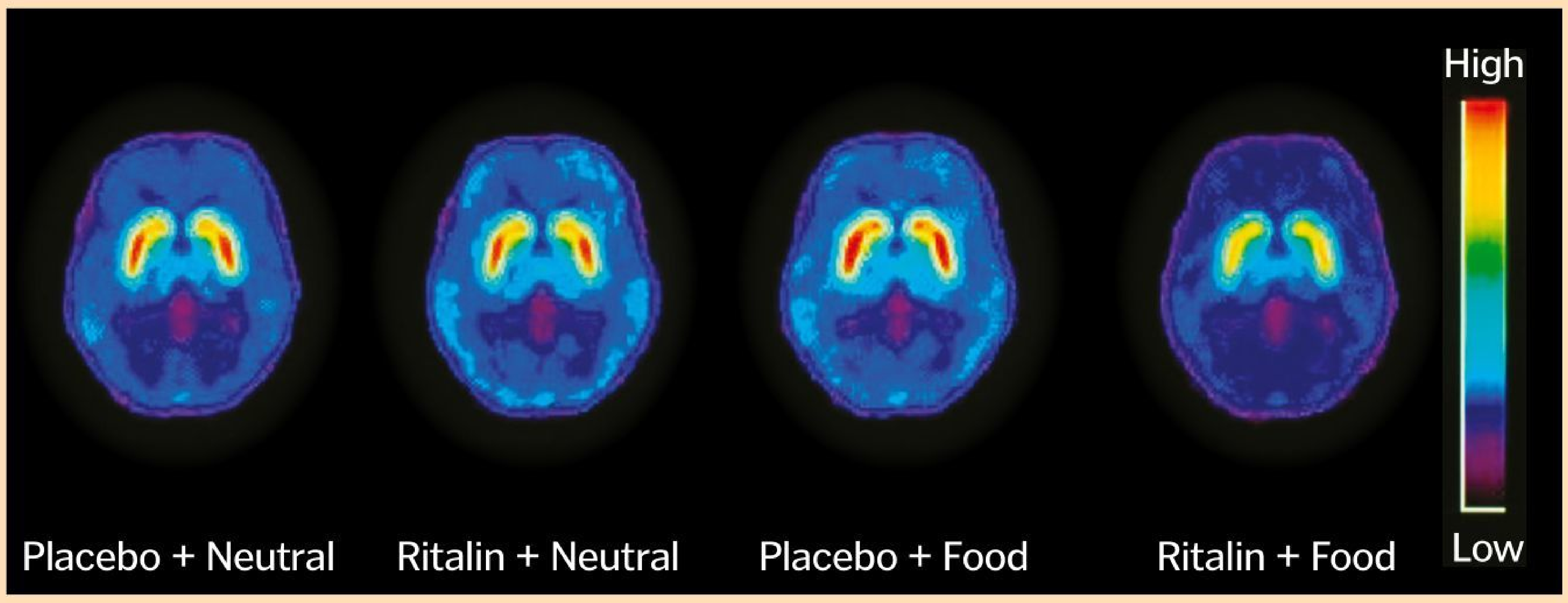
Humans have been programmed through evolution to enjoy fatty and sugary foods; eating them ensures we have enough energy to survive. The hippocampus is involved in gathering sensory information, and processing it for long-term memory storage, and with food cravings, these memories become associated with activation of the brain's reward circuitry. The more we enjoy eating a food, the more likely we are to crave it.

Mental images are thought to play an important role in food cravings and picturing food makes it much harder to resist. But thinking about other visual images can help to curb the cravings and distract your brain.

Digestion happens subconsciously, but you do have a manual override, and what your brain thinks it wants isn't always what it needs.

Food addiction

Research into food addiction is relatively new and the results are hotly debated, but there is increasing evidence that food can elicit some of the same brain responses as addictive substances like cocaine. In overweight people, overeating can become a compulsion that is difficult to control, and has been shown to activate the same reward pathway that lights up when addictive drugs are ingested. In alcoholics, cocaine addicts and heroin addicts, the number of dopamine receptors in the reward pathway is lower than in the rest of the population and the same thing is found in obesity. It is thought that people with fewer dopamine receptors might need to over-stimulate their brains to experience the same rewards as normal people, and therefore turn to alcohol, drugs, or perhaps even food.



Comfort food

When we are feeling stressed or sad, many people turn to comfort foods such as mashed potatoes, beans on toast or macaroni cheese. Carbohydrates not only make us feel warm and full, they actually increase levels of serotonin, sometimes known as the happy hormone.

Sweets

Sugary foods are craved for many reasons, the simplest of which is that your body needs an energy boost. However, eating sugar is just a temporary fix, and as the sugar is rapidly cleared from the blood, the craving will quickly return.

Salty snacks

Animals have what is known as a 'salt appetite', similar to thirst, which drives them to seek out salt when they are running low. However, there is little evidence for an equivalent trait in humans. Men are more likely to crave salty foods than women, though.

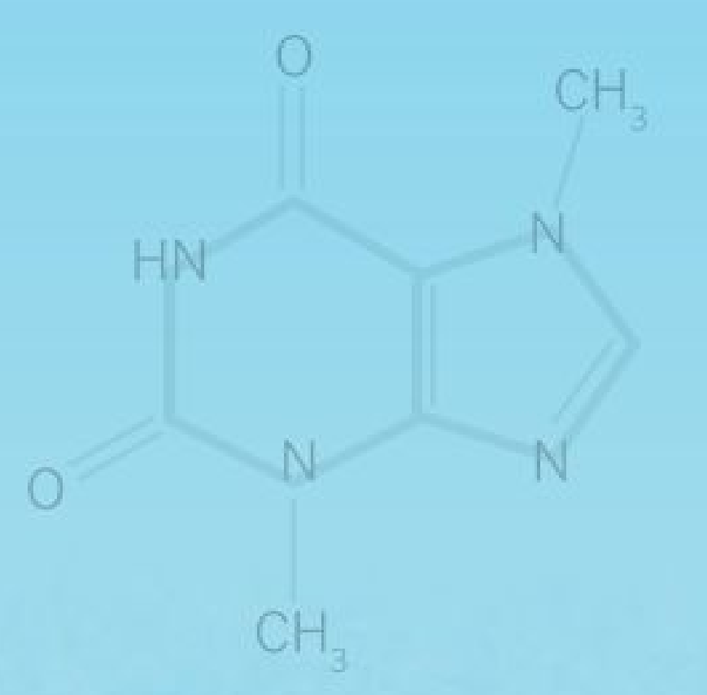
DID YOU KNOW? *The digestive system has its own dedicated nervous system, known as the enteric nervous system*

CHEMISTRY OF FOOD

Take a look at the chemicals behind some of our favourite foods and drinks

Tea

In England, drinking tea is a national pastime. The main chemicals in tea are known as polyphenols, and each cup contains around 200 milligrams (0.007 ounces). The polyphenols are large molecules made up of smaller building blocks, which are known as catechins. When these catechins react with oxygen, they make two types of chemical; theaflavins, which make the orange-brown colour of tea, and thearubigins, which are thought to contribute to the taste. The different amounts of the chemicals present in the tea are very dependent on the life of the plants and the processing of the leaves.



Chocolate

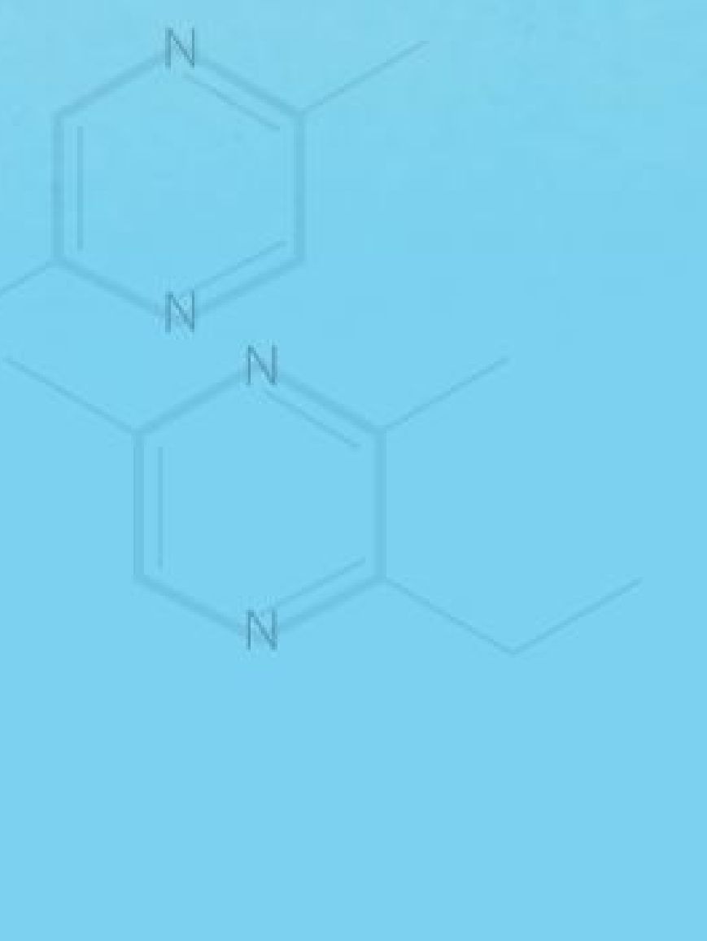
Chocolate is one of the foods most commonly associated with happiness, particularly the hormone serotonin. The chocolate itself does contain the precursor to serotonin, an amino acid known as tryptophan, but this is also found in many other foods, including meat. Chocolate also contains phenylethylamine, a molecule chemically similar to amphetamine, but it is broken down in the digestive system, and does not reach the brain intact. The feel-good factor of chocolate is more likely to be down to its fat and sugar content, and a property known as mouthfeel. Chocolate is among the only foods that melts at close to body temperature.

30CM

THE LENGTH OF AN AVERAGE STOMACH AFTER A MEAL

Coffee

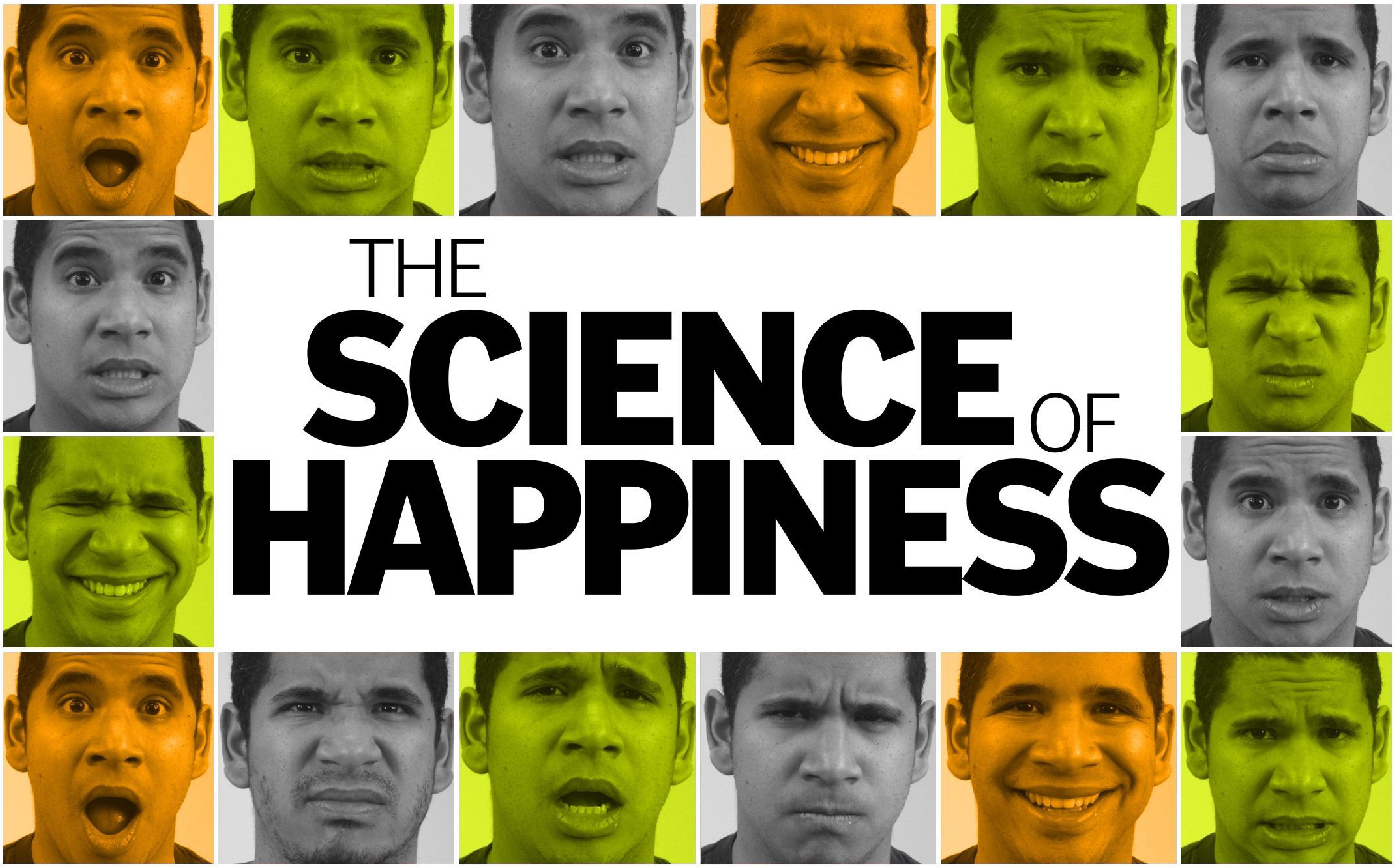
Coffee contains over 1,000 different aroma compounds, responsible for its unmistakable smell. Around 12 per cent of the green coffee bean is made up of a set of chemicals known as chlorogenic acids, and when the beans are roasted, most of these acids begin to break down. Some produce the brown-coloured compounds that give coffee its characteristic dark colour, while others produce the bitter-tasting chemicals responsible for its taste. Coffee also contains high quantities of caffeine, around 100 milligrams (0.0035 ounces) in every cup. It works on receptors in the heart and brain, blocking the action of a natural neurotransmitter and acting as a stimulant.



Bacon

The distinctive smell of bacon is, as most of us have probably experienced, hard to resist. That fact is all down to the chemistry of cooking meat. As the bacon is heated, the amino acids that make up the muscle protein react with reducing sugars present in the bacon fat. This process, known as the Maillard reaction, occurs only at high temperatures and produces over 150 different volatile molecules, each able to interact with different smell receptors in the nose. Most of the delicious smell of bacon is attributed to a group of nitrogen-containing compounds known as pyridines and pyrazines.

© Jynto; Greg Robson; Andreadonetti/ Valentyn75/Dreamstime/ Corneliusz0; Thinkstock; Science Photo Library; DK



THE SCIENCE OF HAPPINESS

Human emotions are governed by a complex mix of chemicals and electricity – learn all about our moody biology…

The human brain weighs just over a kilogram (2.2 pounds) and plays host to an estimated 86 billion neurons, and at least as many supporting glial cells. Signals are transmitted along each nerve electrically, by gradients of charged ions, and each neuron makes hundreds of connections to those around it.

At each of the 300 trillion synapses in the human brain, chemicals known as neurotransmitters relay messages from one nerve to another. Each neurotransmitter has a set of corresponding receptors, which can be activatory or inhibitory, helping nerves to fire, or suppressing their activity. This enormous chemical and electrical system provides the complex network that enables us to feel emotion, from the all-consuming addiction of love, to the raw devastation of grief.

Techniques like functional magnetic resonance imaging (fMRI) have helped reveal areas of the brain involved in processing different emotional responses. This data, in combination with case studies of patients with damage to certain areas of their brains, and information gathered from investigations in animals, has enabled us to draw up a map of emotional connections in the body.

A notable area of the brain when it comes to mood is the limbic system (see opposite) – a small cluster of interconnected regions involved in memory storage and decision-making. The limbic system is directly connected to the olfactory bulb, which processes incoming smell signals from the nose, providing the biological link that allows odours to recall a memory. Research by the Kavli Institute for Systems Neuroscience in Norway found that smell-based memories are triggered with the activation of corresponding brain waves to those experienced on initially experiencing the scent.

The nucleus accumbens links the limbic system to other areas of the brain also involved in the processing of emotion. For instance, the basal ganglia, at the base of the forebrain, has been well studied for its role in the planning and co-ordination of movement, but certain areas also light up in response to positive emotional stimuli and are thought to be involved in reward and reinforcement. Damage to part of the basal ganglia, known as the ventral pallidum, causes anhedonia – the inability to experience pleasure. The orbitofrontal cortex, located above the eyes, also activates in response to positive experiences, and is thought to play a role in evaluating reward versus punishment.

Compound emotions

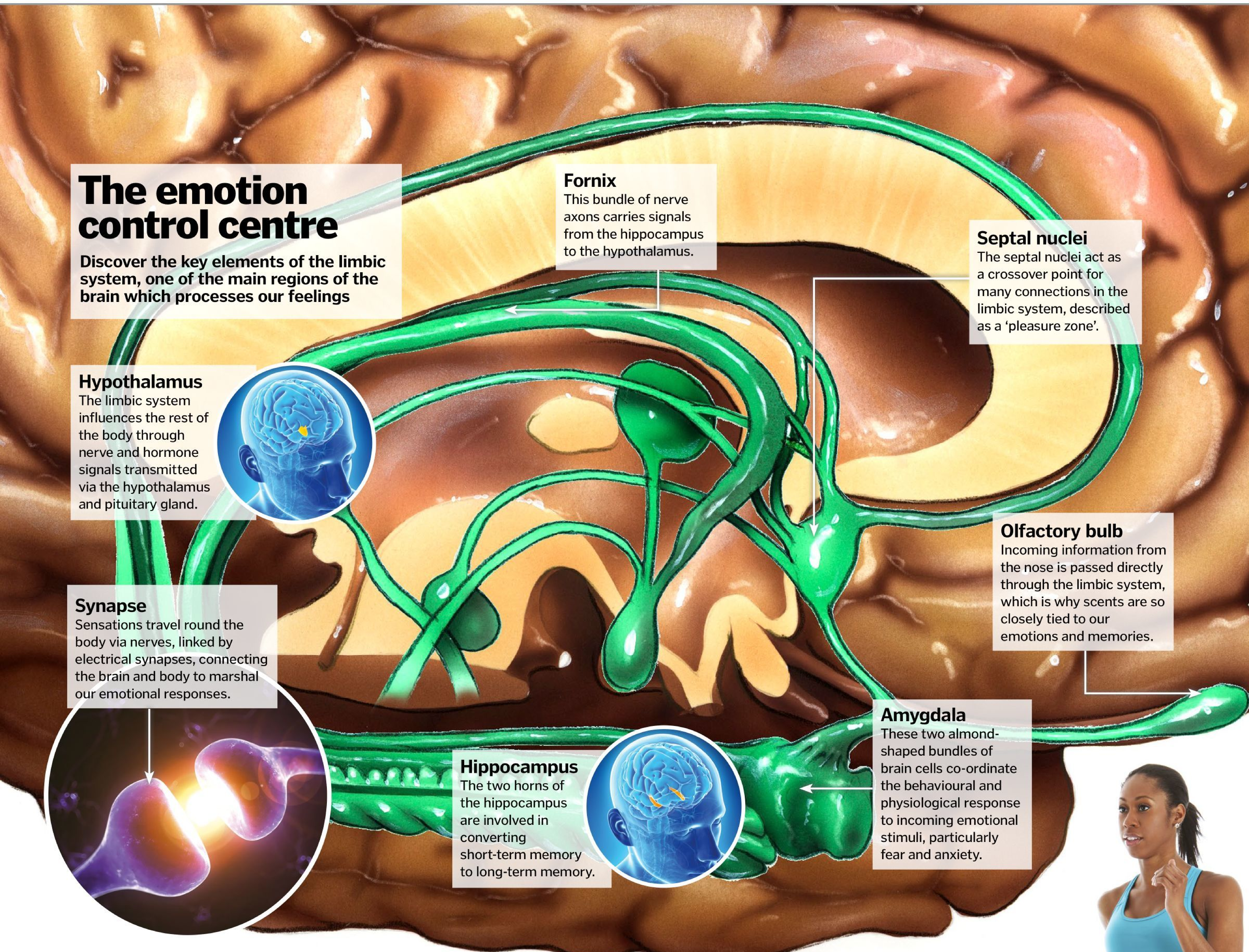
Research by Ohio State University found that we may have as many as 21 distinct and complex emotional expressions – a few demonstrated in the images above. Hybrid emotions include being 'angrily surprised' or 'happily disgusted' and appear when conflicting feelings are experienced simultaneously. For instance, you may be sad something has ended but happy that you have experienced it. Previous studies suggested that we only had six emotions.

Another approach to the study of complex emotions like happiness is to break them down into smaller parts. Pleasure is evolutionarily ancient and is based on a chemical reward system that acts as a biological incentive to repeat beneficial behaviour. There are several

DID YOU KNOW? *Serotonin is found in some insect venom and plant spines; it can cause pain, tingling and nausea*

The emotion control centre

Discover the key elements of the limbic system, one of the main regions of the brain which processes our feelings



Fornix
This bundle of nerve axons carries signals from the hippocampus to the hypothalamus.

Septal nuclei
The septal nuclei act as a crossover point for many connections in the limbic system, described as a 'pleasure zone'.

Hypothalamus
The limbic system influences the rest of the body through nerve and hormone signals transmitted via the hypothalamus and pituitary gland.

Olfactory bulb
Incoming information from the nose is passed directly through the limbic system, which is why scents are so closely tied to our emotions and memories.

Synapse
Sensations travel round the body via nerves, linked by electrical synapses, connecting the brain and body to marshal our emotional responses.

Amygdala
These two almond-shaped bundles of brain cells co-ordinate the behavioural and physiological response to incoming emotional stimuli, particularly fear and anxiety.

Hippocampus
The two horns of the hippocampus are involved in converting short-term memory to long-term memory.

How do drugs alter our mood?

Humans have been modifying their brain chemistry for medical, religious and recreational purposes for centuries, despite the many risks. Stimulants like caffeine, nicotine, cocaine and amphetamine affect the release of the fight-or-flight chemicals adrenaline and noradrenaline, increasing alertness. While euphoriants like MDMA cause a surge of serotonin, which in turn leads to the release of bonding hormone oxytocin, resulting in a sense of euphoria.

Depressants, including sedatives, hypnotics and alcohol, work on the GABA receptor system to dampen brain activity. GABA is an inhibitory neurotransmitter, and blocks nerve activity, resulting in relaxation and reduced anxiety. Some depressants have anti-convulsant effects, so are used as a treatment for epilepsy.

Opioids also modulate nerve signals. Opium, along with related drugs like morphine, have a similar structure to natural endorphins and bind to their receptors in the brain and spinal cord, resulting in pain relief and euphoria.

Emotional messengers

Dopamine

This neurotransmitter feeds the reward pathway in the brain and is involved in motivation, drive, pleasure and addiction. Abnormally high levels of dopamine are linked to loss of contact with reality, delusions and lack of emotion, while low levels are linked to addictive behaviour and risk taking.

Noradrenaline

Related to adrenaline, this neurotransmitter is a stress hormone that co-ordinates the fight-or-flight response. It mediates many of the physical components of emotion, including raised heart rate, and also acts in the brain to enhance alertness, cognition and decision-making behaviour.

GABA

Gamma-aminobutyric acid (GABA) is the brain's main inhibitory neurotransmitter. It subdues nerve transmission, allowing neurons time to recover. Increased GABA activity reduces anxiety and stress.

Serotonin

First recognised for its ability to constrict blood vessels, serotonin has since become widely regarded as the 'happiness hormone'. Chemically known as 5-hydroxytryptamine (5-HT), increasing the serotonin level in the brain is the main goal of medical antidepressants.

Beta-endorphin

Endorphins are natural opioids, produced in response to pain, excitement and exercise (pictured). Beta-endorphin binds to the same mu receptors as pain-relieving morphine. Present on nerves in the brain and spinal cord, they modulate neural activity, causing mild sedation, relieving pain and inducing joy.

Oxytocin

Often described as the 'bonding hormone' or 'love hormone', oxytocin is unique to mammals. Although research is still in its infancy, oxytocin is thought to play a role in intimacy, childbirth, sexual arousal, trust and pair bonding.

'reward pathways' in the brain, but the most studied is the mesolimbic pathway.

The pathway transmits dopamine signals from nerves in the middle of the brain, upward and forward, to the limbic system and the prefrontal cortex, which are involved in emotional processing. Under normal conditions, this pathway serves as a motivator for positive actions, producing pleasurable feelings that reinforce beneficial behaviour like eating high-calorie food, social interaction and reproduction. Activation of the pathway also aids in memory retention, increasing the likelihood that the action will be repeated in the future.

Unfortunately, the pleasurable feedback is so strong that abuse of the pathway is common. Many illicit substances, including cocaine, amphetamine and MDMA, affect the mesolimbic pathway, resulting in a pleasurable reward, but also contributing to habituation and addiction.

It's not all about the brain though. The feelings associated with emotions are the result of a complex mixture of incoming sensory messages that come from all over the body.

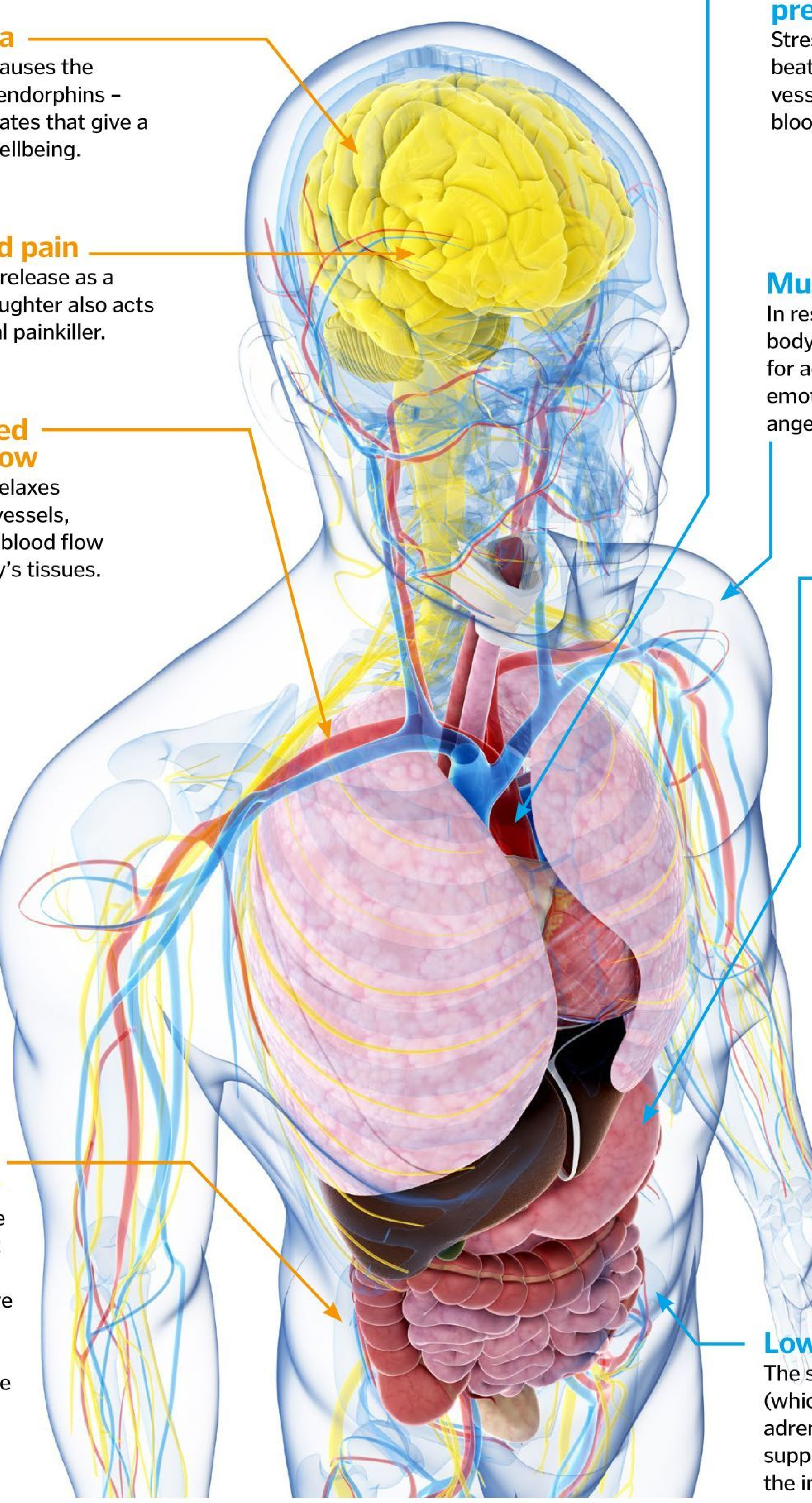
The autonomic nervous system (more commonly known as ANS) is the subconscious arm of the peripheral nervous system, and is responsible for bodily functions that are not

Can we fake a smile?

Faking emotions is harder than it seems. Humans are social animals and have evolved extremely good facial recognition skills – so if something isn't quite right, we are quick to notice. The muscles around our mouths are under fine voluntary nerve control, which not only provides the range of motion required for speech, but also enables us to fake a smile. But people are not easily deceived. Facial expressions involve a multitude of subtle, involuntary muscle movements, and re-creating them is incredibly difficult. The forehead and eyebrows are particularly challenging, as the muscles are mostly under subconscious control. It is hard to achieve the same expression with voluntary muscle contraction, and our eyes are often the biggest giveaway when a smile isn't genuine.

Laughter vs stress

These two opposing states have very different effects on the body, as we reveal here…



Euphoria
Laughter causes the release of endorphins – natural opiates that give a sense of wellbeing.

Reduced pain
Endorphin release as a result of laughter also acts as a natural painkiller.

Increased blood flow
Laughing relaxes the blood vessels, increasing blood flow to the body's tissues.

Improved immunity
There is some evidence that laughter can have a positive effect on the function of the immune system.

Raised blood pressure
Stress causes the heart to beat faster and the blood vessels to constrict, raising blood pressure.

Muscle tension
In response to stress, the body prepares the muscles for activity; very strong emotions like anxiety and anger can lead to shaking.

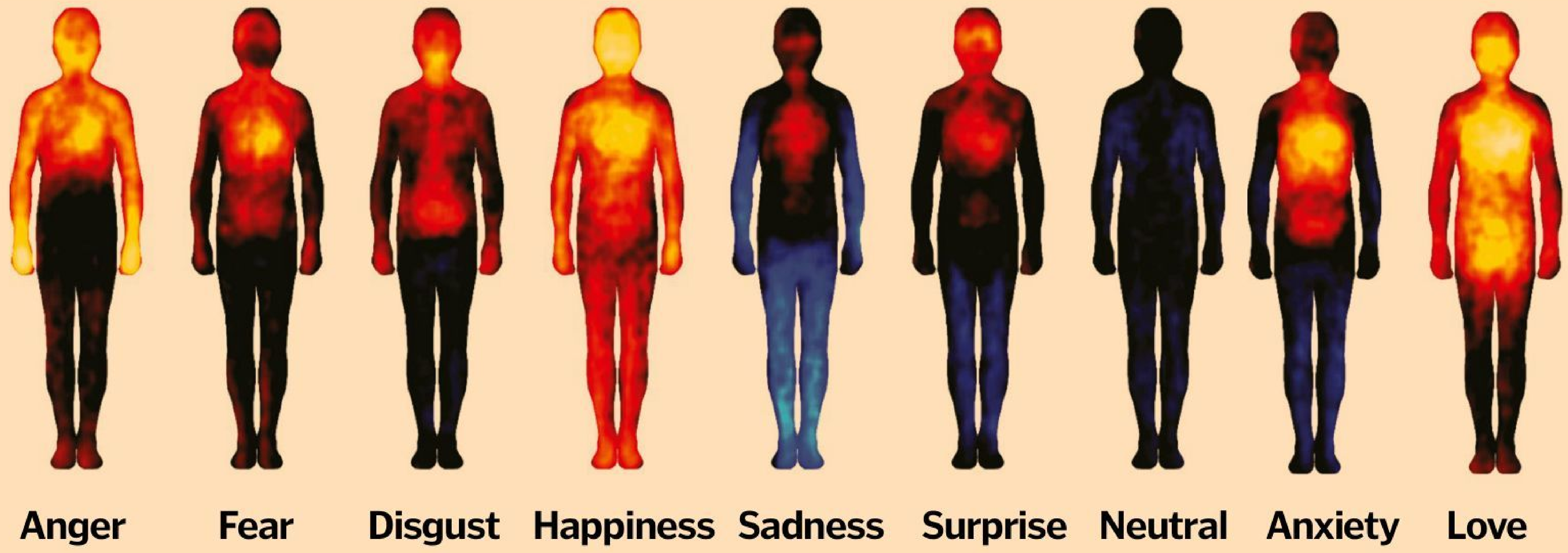
Stomach cramps
In emotionally challenging situations, the brain diverts blood away from the digestive system, prioritising the muscles and brain.

Sweaty palms
As part of the fight-or-flight response, the sympathetic nervous system activates sweat glands on the hands, feet and in the armpits.

Lowered immunity
The stress hormone cortisol (which is produced in the adrenal glands; not shown) suppresses the activity of the immune system.

Mapping out emotions

The complex human emotions are the result of sensory signals from the rest of the body. Researchers at Finland's Aalto University charted the areas of the body most commonly associated with different feelings to produce maps of where we experience the major emotions. The images demonstrate how different emotions trigger different levels of sensation around the body. Here high levels of sensation are represented with warmer hues, and vice versa.



DID YOU KNOW? *Two-thirds of couples can smell each other's emotions and detect a difference between fear and happiness*

Emotions are often influenced by physical stimuli, be it food, behaviour or environmental factors like sunlight

under our voluntary control, such as heart rate, digestion and sweating; it too is wired in to the limbic system.

The ANS has two distinct components with opposing functions. The sympathetic nervous system uses the neurotransmitters adrenaline and noradrenaline to prepare the body for 'fight or flight', raising the heart rate and mobilising resources to fuel the muscles. The parasympathetic nervous system uses acetylcholine to allow the body to rest and digest, slowing the heart and breathing, and diverting the blood supply to the gut.

Sensory feedback produced by the effects of the autonomic nervous system contribute to many of the familiar feelings associated with emotions. Stimulation of the heart by adrenaline and noradrenaline as part of the fight-or-flight response produces the rapid palpitations associated with anger, fear and embarrassment. Its actions on the digestive system cause 'butterflies in the stomach', and activity at the glands on the hands, feet and in the armpits, leads to sweating when nervous.

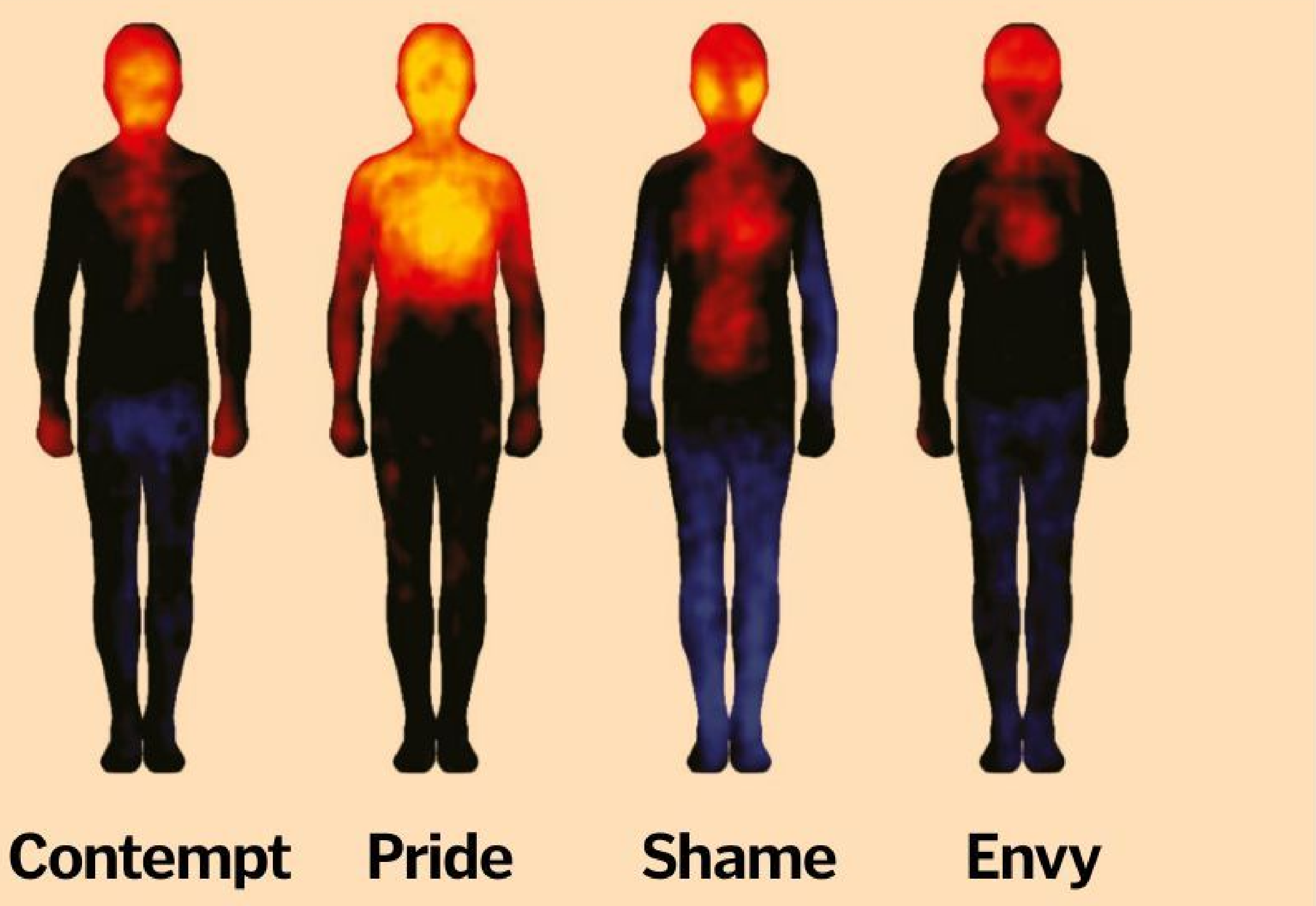
More passive emotions, like sadness or contentment, on the other hand, require little physical response, and the parasympathetic nervous system takes control of the heart, slowing its rate. Feelings of contentment and relief are often accompanied by deep, slow breathing – another indicator of parasympathetic activity.

The limbic system is also connected to the body via the hypothalamus. This small region, located on the underside of the brain, links the nervous system to the endocrine system, which produces hormones – some of which are key mediators of mood and emotion. For example, corticotropin-releasing hormone is produced in response to stress, and leads to the release of the stress hormone cortisol from the adrenal glands above the kidneys.

The regulation of emotion is not just restricted to one area of the brain – it involves almost the entire body. Reducing the bewildering complexity of human emotion down to anatomy, physiology and, ultimately, brain chemistry, might seem clinical and overly simplistic, but in reality, the fact that humans are capable of experiencing such an extraordinary range of abstract feelings is one of the greatest wonders of biology, with many chemical puzzles still waiting to be solved in this area.

Fight or flight

The autonomic nervous system is responsible for the control of heart rate, blood pressure and respiration, and governs the function of most of the internal organs. It's divided into two parts. The sympathetic nervous system is responsible for the fight-or-flight response and is behind raised heart rate, sweating, nausea and shaking associated with action-based emotions like anger and anxiety. While the parasympathetic nervous system has the opposite effect and plays a bigger role in more passive emotions like sorrow and contentment.



> *"There are several 'reward pathways' in the brain"*

5 happiest countries

(UN's World Happiness Report, 2017)

1. Norway
2. Denmark
3. Iceland
4. Switzerland
5. Finland

3 unhappiest occupations in the UK (2014)

1. Publican
2. Elementary construction
3. Debt collection

HAPPIEST and SADDEST states in the United States

(Gallup-Healthways Well-Being Index, 2013)

HAPPIEST	SADDEST
1. North Dakota	1. West Virginia
2. South Dakota	2. Kentucky
3. Nebraska	3. Mississippi

25%

Of 129 gold medal ceremonies at the London 2012 Olympics, 25 per cent of FEMALE ATHLETES CRIED, compared to just eight per cent of male competitors

SMILIEST country Brazil

Travel app Jetpac analysed INSTAGRAM IMAGES BY COUNTRY, ranking photos based on whether the subject had a wide grin or a tight-lipped smile. Brazil finished first, while the USA lagged behind in 33rd place. The UK ranked 62nd and Japan came bottom

23 69

LIFE SATISFACTION peaks at the AGES of 23 and 69, according to the London School of Economics (2013)

© Alamy; Thinkstock; Lauri Nummenmaa/Aalto University; Ohio State University

The gut-brain axis

How does the bacteria in your gut act like a 'second brain'?

We all know that our mood and behaviour is controlled by the brain, but are we overlooking another important aspect of our neurobiology?

There is an increasing amount of evidence to suggest that the activity of bacteria in your gut can significantly affect your brain. This relationship is called the gut-brain axis, and while its exact mechanisms and significance haven't been fully figured out, it is thought that the microbes colonising your digestive tract are responsible for complex interactions between your digestive system and the nervous, endocrine and immune systems.

Your intestines are filled with bacteria. When you think of bacteria you probably think of the germs that make you sick, but we actually have a lot to thank these tiny microorganisms for. We rely on 'good' bacteria to help break down food, produce vital nutrients and defend us against harmful bacteria. But this could just be the tip of the iceberg. Scientists speculate that gut microbes can send signals to the brain via three different methods.

The first involves bacteria releasing neurotransmitters (chemicals that help to transmit nerve impulses) to trigger the neurons in your digestive tract, which in turn send signals to your brain via the vagus nerve. Some studies have shown that certain species of gut bacteria can produce serotonin, an important neurotransmitter that plays a role in regulating your appetite and mood.

A second proposed method is that microbes in the gut produce molecules called metabolites as by-products when they break down our food. These metabolites can stimulate an increase in the production of neurotransmitters by cells that line the gut (epithelial cells), which activate the vagus nerve. For example, a recent study found that some gut microbes can produce the fatty acids butyrate and tyramine, which promote the production of serotonin by certain cells.

The third hypothesis is that gut bacteria can influence the brain indirectly by triggering the immune system. Gut bacteria can stimulate immune cells to produce small proteins called cytokines, which travel through the bloodstream to the brain. It is thought that these proteins can influence the development and activity of microglia (the brain's immune cells), which are responsible for removing damaged cells at an injury site. Researchers believe microglia also play a role in the regulation of appetite and metabolism.

Although there are few human studies at the moment, animal studies have linked the activity of gut bacteria to a variety of conditions, including Parkinson's disease, obesity, depression, anxiety, schizophrenia and cardiovascular disease, and they may also cause certain types of strokes.

While much more research will be needed to further investigate these initial findings, if links are confirmed it could revolutionise how we treat certain neurological disorders. Perhaps in the future doctors will be prescribing probiotic diets to supplement treatments.

Bacterial boost

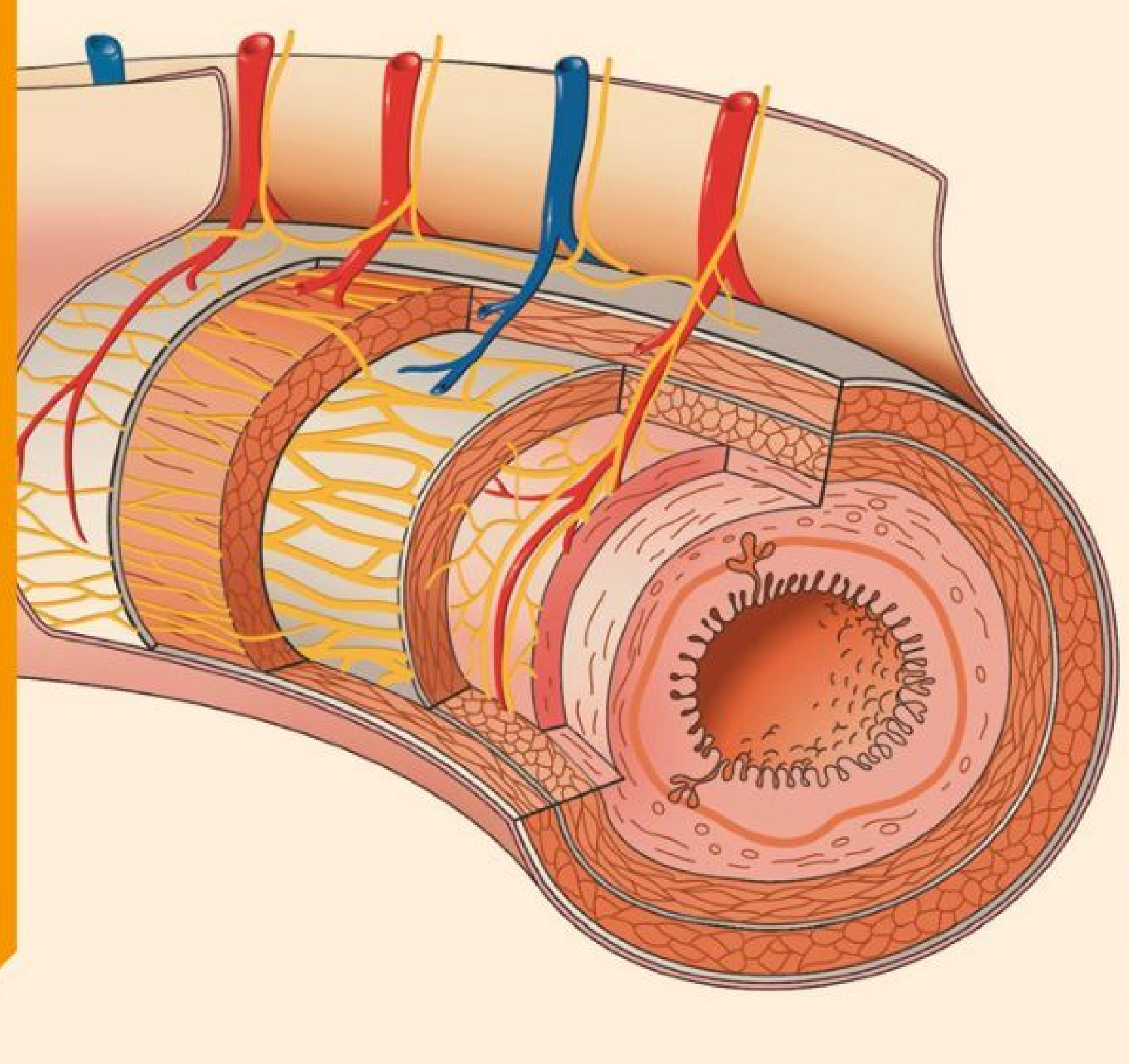
Two recent studies have shown that patients' gut bacteria can influence how well they respond to particular cancer treatments. Both studies, one from France and one from the US, collected data from patients undergoing immunotherapy, which help to combat cancer by enabling the body's immune cells to recognise and attack tumours.

The French study involved 249 patients receiving immunotherapy for kidney, bladder or lung cancers, 69 of whom had taken antibiotics for routine infections. Antibiotics disrupt the microbiome, affecting both 'good' and 'bad' bacteria. On average, patients who took antibiotics during treatment were more likely to have relapses and did not survive as long as those who didn't. The authors then compared the differences in the patients' microbiomes and found that the presence a species called *Akkermansia muciniphila* was linked to the improved immunotherapy results.

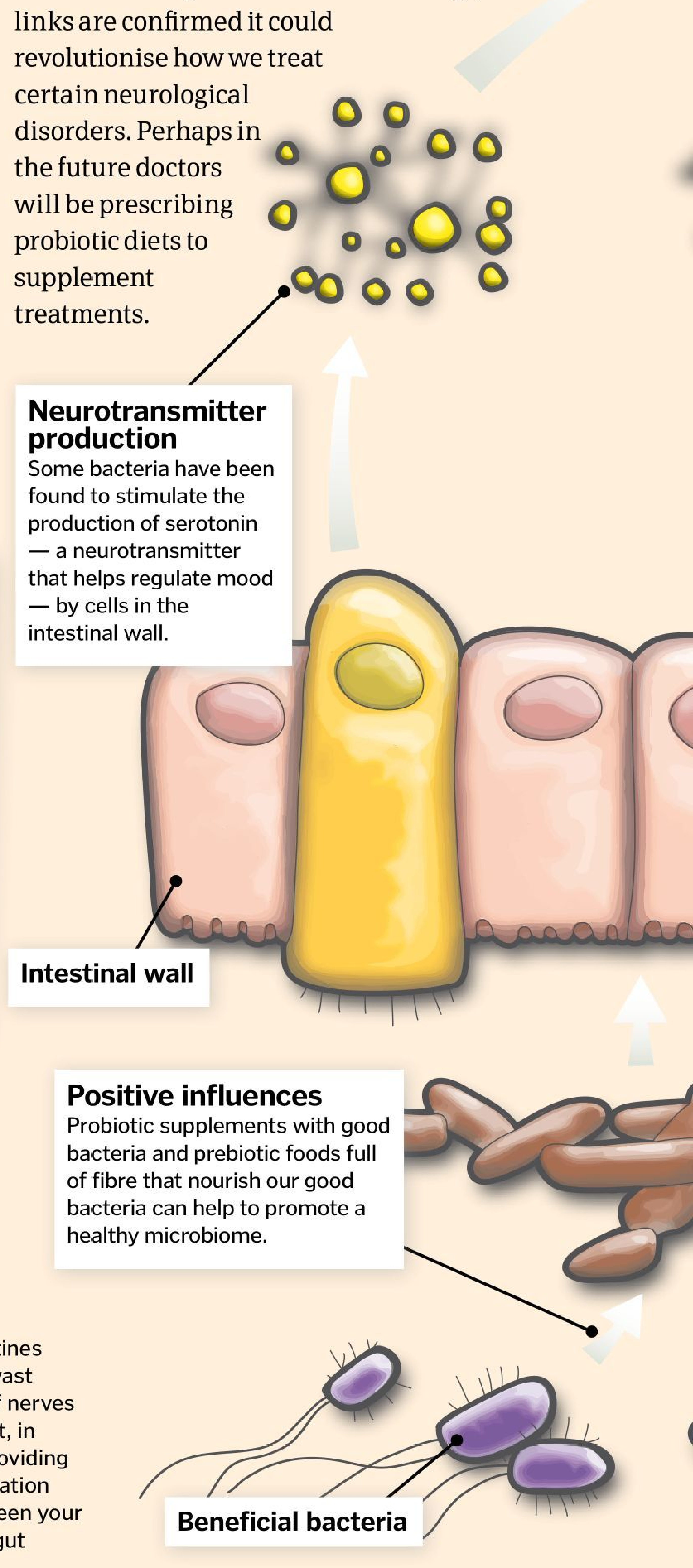
The US study also compared the different gut bacteria present in 112 melanoma patients. Patients who responded well to treatment were more likely to have more diverse microbiomes and higher numbers of certain beneficial species including *Clostridiales* and *Faecalibacterium*. Patients with more of these 'good' bacteria were found to have more cancer-killing immune cells in their tumours.

The results from both studies hold a lot of promise. The hypothesis is that by supporting a healthy microbiome, immunotherapy is more likely to be effective at shrinking tumours.

Scientists are only just beginning to understand the impact your microbiome can have on your brain



Your intestines contain a vast network of nerves (shown left, in yellow), providing communication links between your brain and gut



Neurotransmitter production
Some bacteria have been found to stimulate the production of serotonin — a neurotransmitter that helps regulate mood — by cells in the intestinal wall.

Intestinal wall

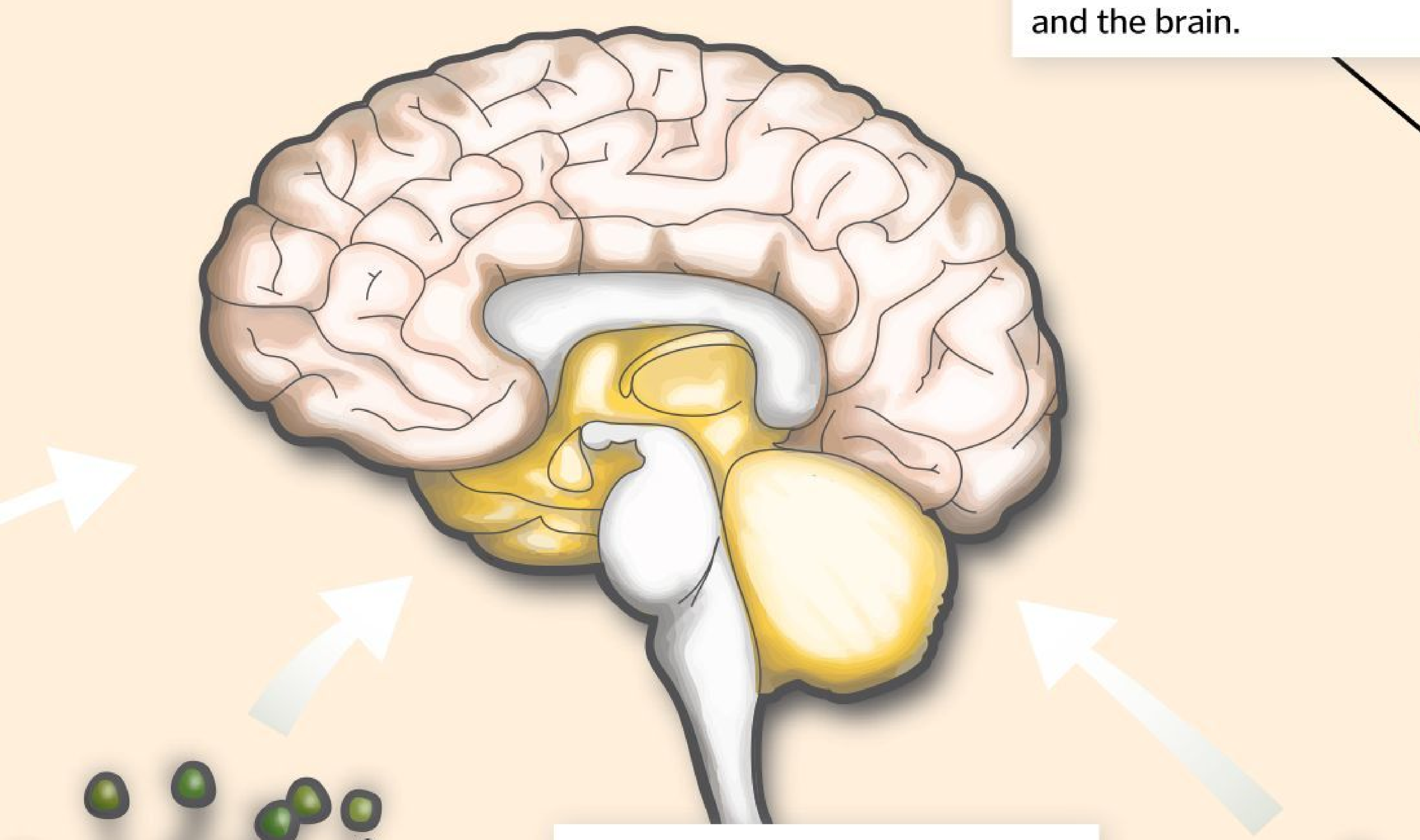
Positive influences
Probiotic supplements with good bacteria and prebiotic foods full of fibre that nourish our good bacteria can help to promote a healthy microbiome.

Beneficial bacteria

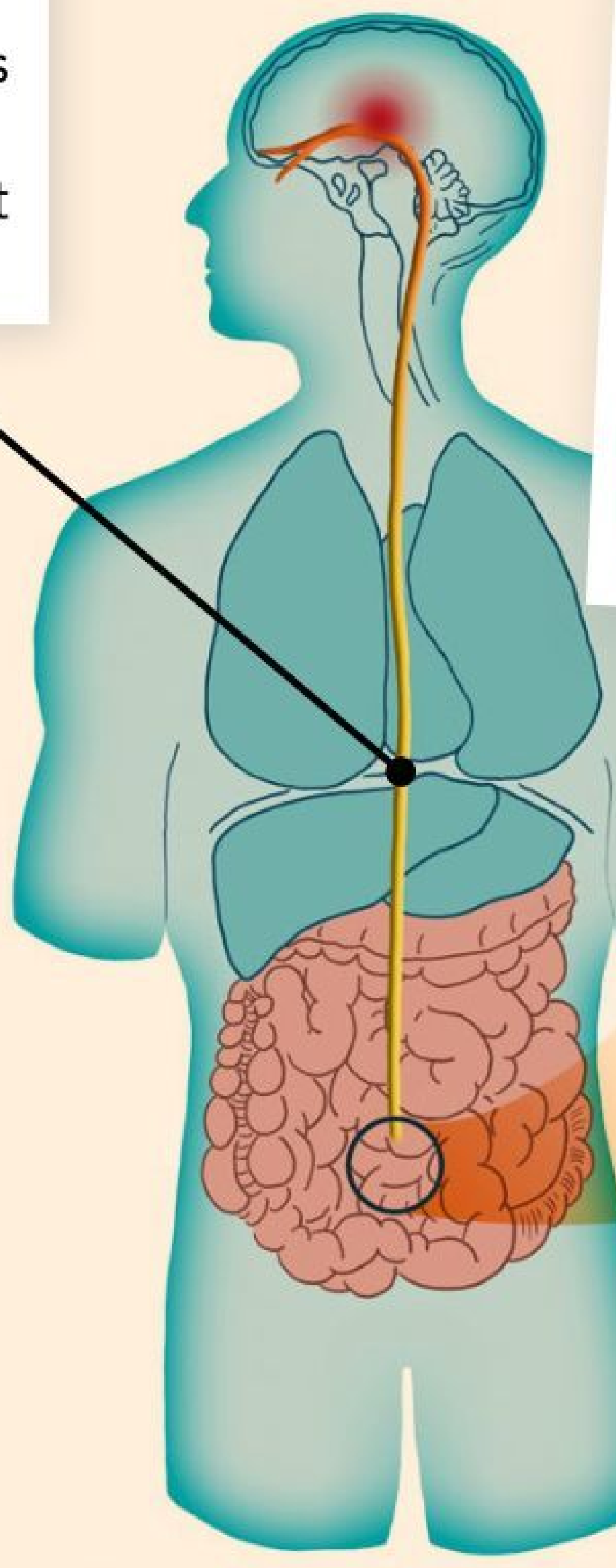
DID YOU KNOW? *There are over 100 trillion microbes in the human gut!*

Gut feeling

How can your microbiome influence your brain?



Immune stimulation
Bacteria can encourage immune cells to release small proteins called cytokines, which can affect immune cells in the brain.



Vagus nerve
The vagus nerve provides a communication pathway between the gut and the brain.

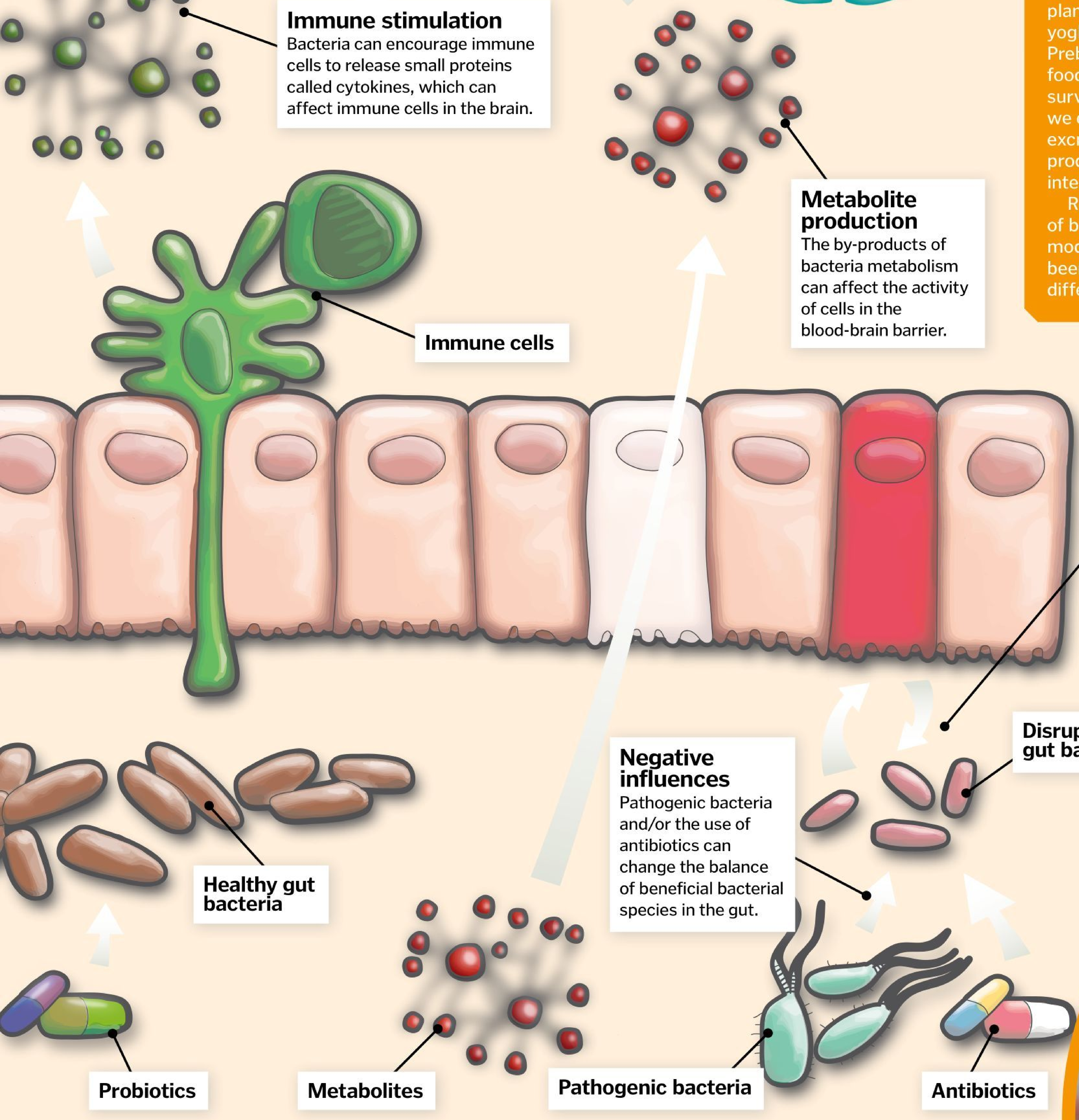
Fermented foods, such as sauerkraut and kimchi, contain probiotics

Probiotics and prebiotics

Given the potential impacts our gut bacteria can have on our overall health, the old adage that states 'you are what you eat' is becoming increasingly appropriate.

We can promote the growth of good bacteria through our diets by incorporating probiotics (foods containing live good bacteria) and prebiotics (foods containing beneficial plant fibres). Probiotics can be found in certain yoghurts, cheeses and fermented foods. Prebiotics, on the other hand, are used as a food source for beneficial bacteria to grow and survive in the gut. When they digest the fibre we eat from vegetables, nuts and fruits they excrete short-chain fatty acids as waste products, which are great for nourishing our intestines and reducing inflammation.

Research suggests we need a diverse range of bacteria to have a really healthy gut, but modern high-fat and high-sugar diets have been found to decrease the number of different species living in our intestines.



Metabolite production
The by-products of bacteria metabolism can affect the activity of cells in the blood-brain barrier.

Immune cells

Two-way street
Gut health and function can influence gut bacteria activity and vice versa.

Negative influences
Pathogenic bacteria and/or the use of antibiotics can change the balance of beneficial bacterial species in the gut.

Disrupted gut bacteria

Healthy gut bacteria

Probiotics

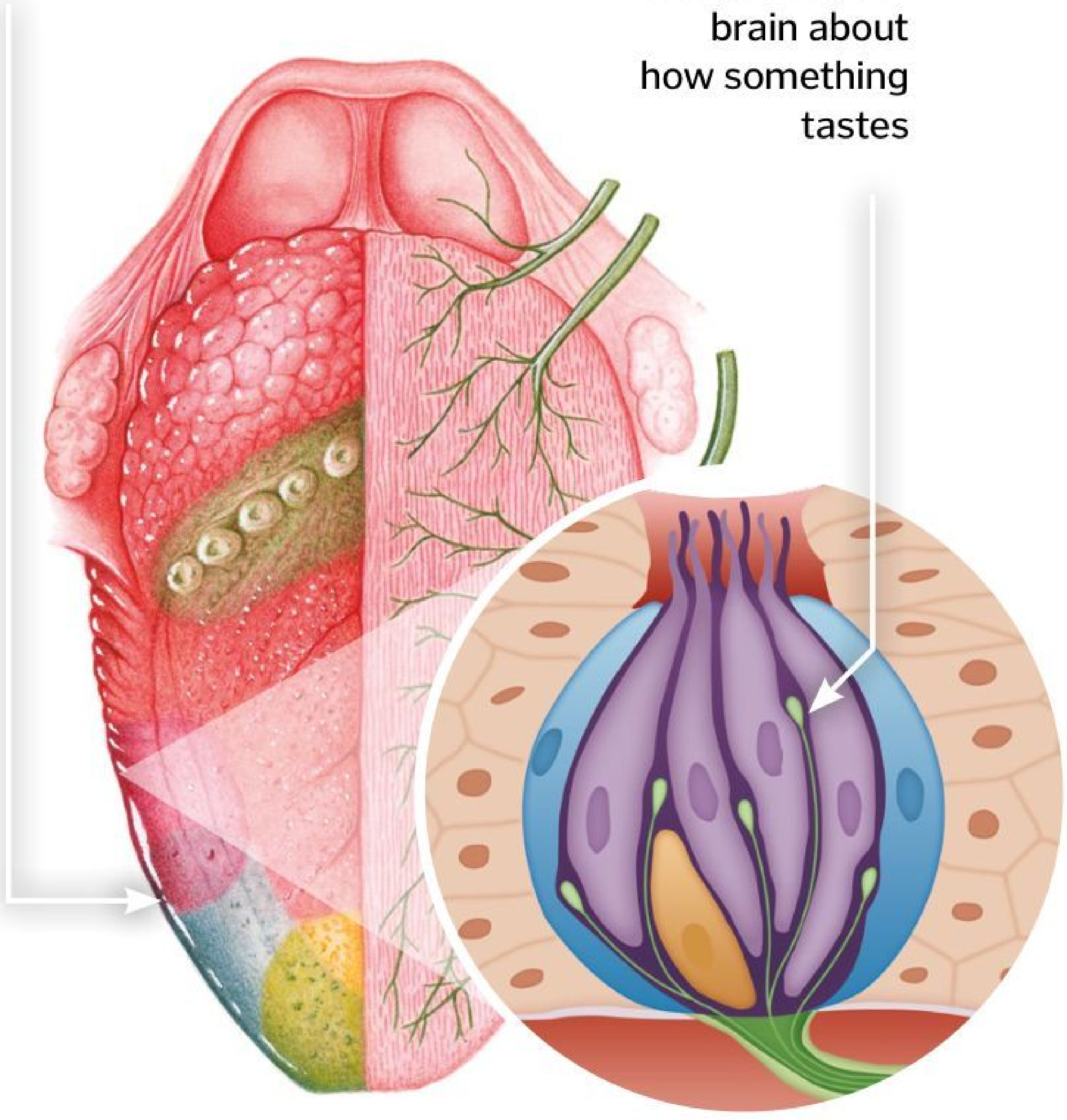
Metabolites

Pathogenic bacteria

Antibiotics

A study involving gut microbe transplants between mice found that certain behavioural traits were also transferred, ie a previously shy mouse would explore more after receiving transplants of bacteria from a more adventurous mouse

© Thinkstock; Getty; Illustration by The Art Agency/ Nick Sellers



Taste qualities are found in all areas of the tongue, although some regions are more sensitive than others

Your taste buds have very tiny, sensitive hairs called microvilli which send messages to your brain about how something tastes

The five basic human tastes

Building a map of the tongue

There is general agreement that humans have five basic tastes, although the fifth taste 'primary' has only been recently officially recognised. Sweetness, bitterness, sourness and saltiness were joined by savouriness in 2002. Several other sensations that the tongue can recognise have been identified but are not classified as tastes.

Sweetness is associated primarily with simple carbohydrates – of which sugar is one of the most common. The way sweetness is detected is complex and only recently has the current model of multiple binding sites between the receptors and sweet substance itself been proposed and accepted. A sweet taste infers that the substance is high in energy and studies have shown that newborns in particular, who need a high calorie intake to grow, demonstrate a preference for sugar concentrations sweeter than lactose, which is found in breast milk.

Bitterness can be detected in very low levels and is generally perceived to be an unpleasant or sharp taste. Many toxic substances in nature are known to be bitter and there is an argument proposed by evolutionary scientists that bitterness sensitivity is an evolutionary defence mechanism. Humans, however, have now developed various techniques to make previous inedible bitter substances edible through reducing their toxicity, often through cooking.

The taste of saltiness is produced by the presence of sodium ions, or other closely related alkali metal ions. Potassium and lithium produce a similar taste as they are most closely related to sodium.

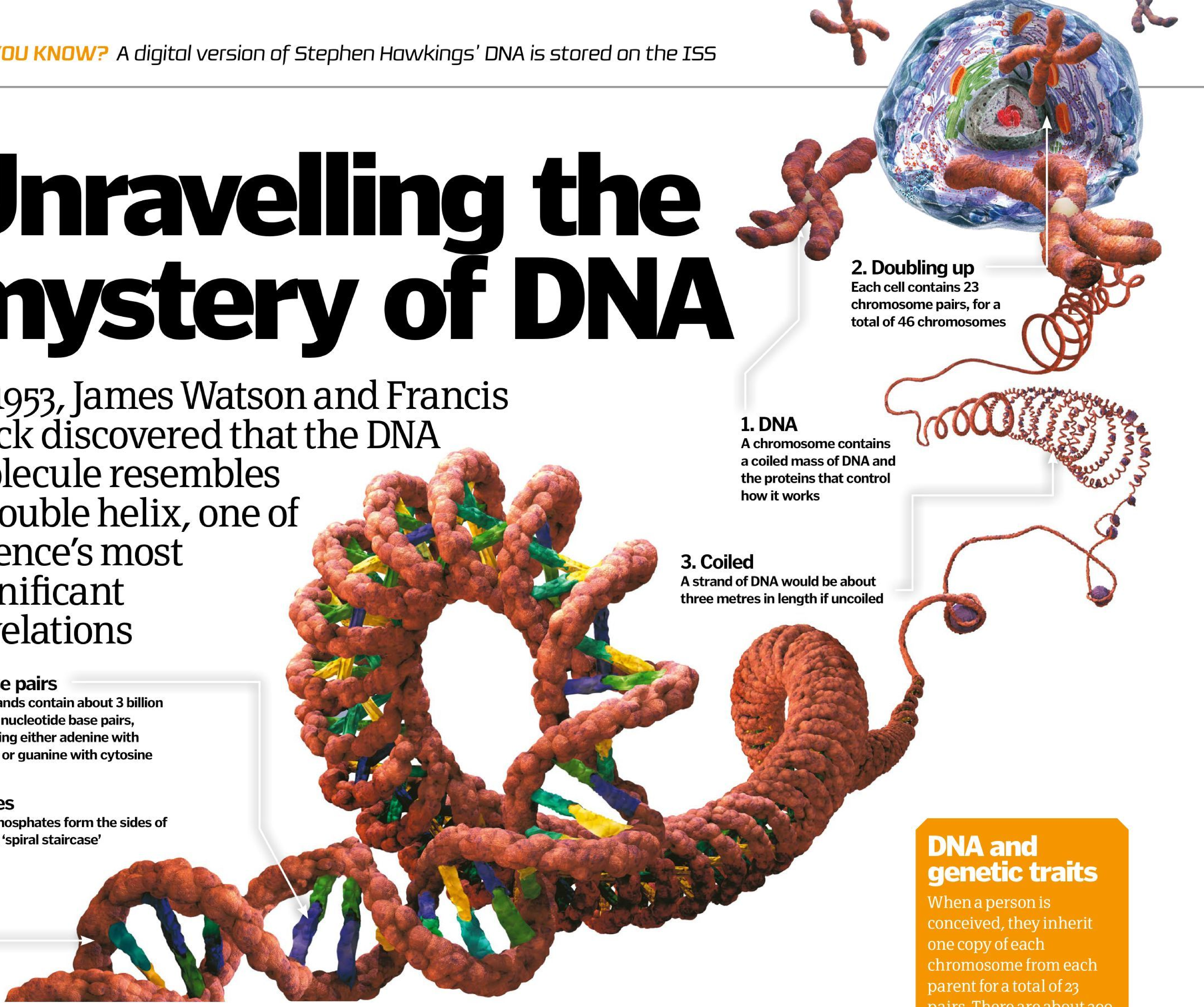
Sourness detects acidity. The way we measure the degree of sourness is through rating sour substances against dilute hydrochloric. The mechanism involved in detecting sourness is similar to saltiness in that taste is caused by a concentration of ions – in this case hydrogen ions.

Savouriness is the newest of the recognised basic tastes and the taste is produced by fermented or aged foods. Glutamate is a common compound that can cause this taste and consequently savouriness is considered fundamental to Eastern cuisine.

DID YOU KNOW? *A digital version of Stephen Hawkings' DNA is stored on the ISS*

Unravelling the mystery of DNA

In 1953, James Watson and Francis Crick discovered that the DNA molecule resembles a double helix, one of science's most significant revelations



1. DNA
A chromosome contains a coiled mass of DNA and the proteins that control how it works

2. Doubling up
Each cell contains 23 chromosome pairs, for a total of 46 chromosomes

3. Coiled
A strand of DNA would be about three metres in length if uncoiled

4. Base pairs
DNA strands contain about 3 billion of these nucleotide base pairs, comprising either adenine with thymine or guanine with cytosine

5. Sides
Sugar-phosphates form the sides of the DNA 'spiral staircase'

Deoxyribonucleic acid, better known as DNA, is the building block of all cells. DNA not only makes the proteins that determine our biological traits, it also gets copied and passed from generation to generation. Changes in DNA over time result in the evolution of traits in a species. Although scientists had learned about DNA and suspected its genetic function since the 1890s, its exact structure wasn't known until 1953.

Cambridge University scientists James Watson and Francis Crick won the 1962 Nobel Prize in Medicine, along with Maurice Wilkins, for discovering that the molecule was a double helix – two ladder-like strands twisted together that resemble a spiral staircase.

These long molecules are twisted, along with various proteins, into a single chromosome. While DNA structure looks complicated, it comprises just four sugars called nucleotide bases: adenine (A), thymine (T), cytosine (C) and guanine (G). These four sugars are strung together to form a sequence, similar to the way that letters of the alphabet form words, and words form sentences. Groups of three nucleotides form 'words' called codons, which form 'sentences' called genes. These genes contain information on how and when to build a protein from a combination of 20 different amino acids.

To build a protein, DNA is copied to a type of RNA (ribonucleic acid) called messenger RNA (mRNA). Two types of special RNA molecules, called transfer RNA (tRNA) and ribosomes (rRNA), use amino acids to build the protein using the pattern described in the mRNA. Sometimes several different proteins are made from the mRNA. This is called protein synthesis.

When a cell needs to reproduce, all of its genetic information must copy over to the new cells. This means that the DNA must replicate itself. Enzymes, hormones and other chemicals in the body drive this process. Essentially the double helix zips apart and enzymes copy the codons, check the copies for accuracy, and seal up the strands. The frequency with which replication occurs depends on the type of cell in which the DNA resides. Cells in our skin, for example, are constantly dividing, so the DNA in those cells is constantly replicating itself.

Sometimes there are minor changes made in the processes of DNA replication and protein synthesis. Because there are some repeater codons, these variations don't always cause a problem. Often they result in a positive outcome, such as increased survival of certain types of diseases. However, depending on the variation, mutations can occur that can ultimately result in hereditary diseases.

DNA and genetic traits

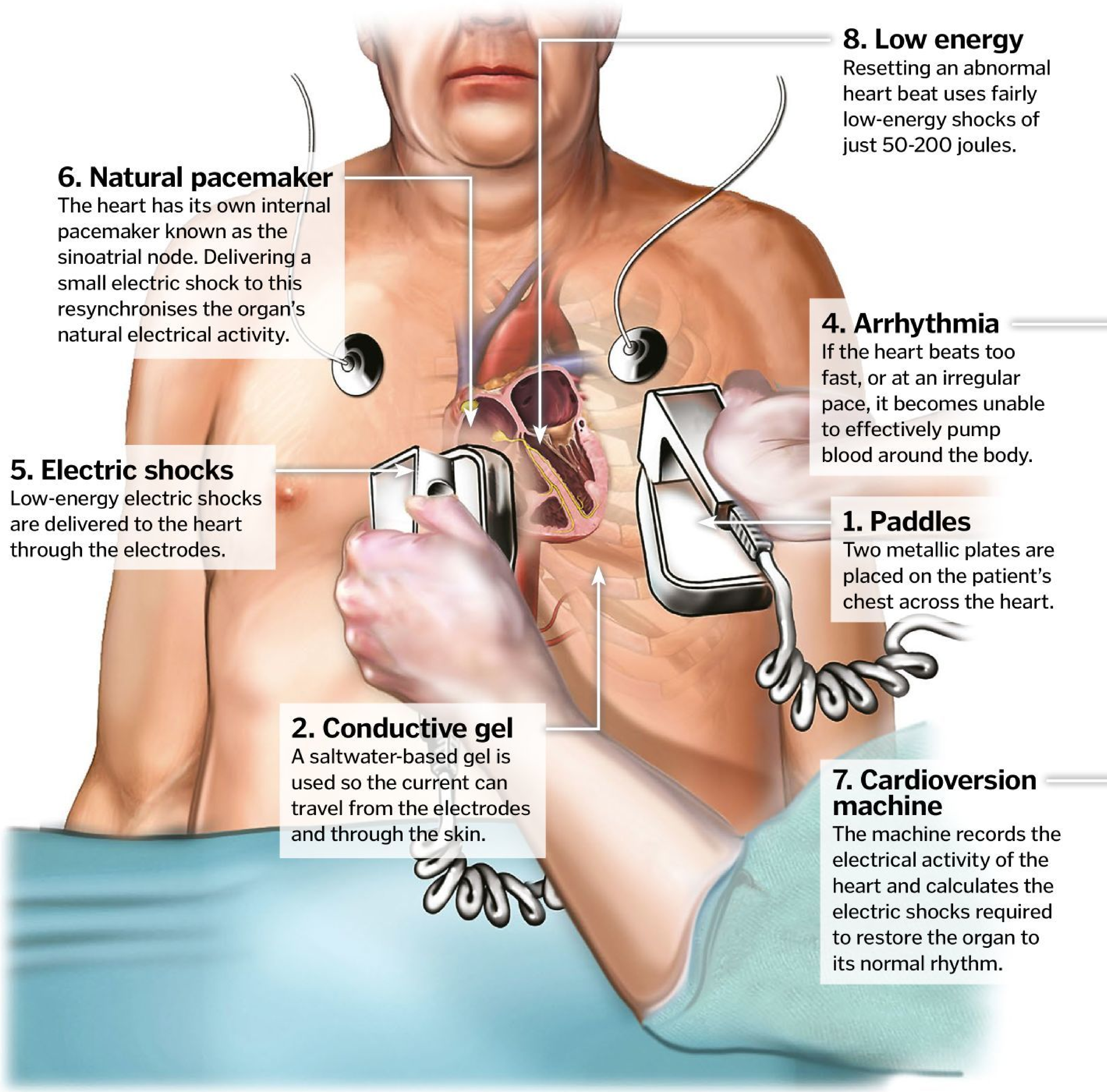
When a person is conceived, they inherit one copy of each chromosome from each parent for a total of 23 pairs. There are about 200 inherited traits that are determined by these genes, including physical and behavioural. We can also inherit a predisposition towards getting a particular disease or disorder. These genetic variations are called alleles. Some are dominant, while others are recessive.

While some traits are determined by a single gene, others come from multiple genes, the environment or a combination. There are multiple genes for determining eye colour, for example, but there's no known gene for being extraordinarily good at playing a specific sport. The latter is likely a combination of genes, health, nutrition and other environmental factors.

Image © DK Images

Correcting heart rhythms

How can a little electricity be used to fix a heart that's beating off-kilter?



1. Paddles
Two metallic plates are placed on the patient's chest across the heart.

2. Conductive gel
A saltwater-based gel is used so the current can travel from the electrodes and through the skin.

3. Timing the shock
The heart is vulnerable when it is between beats, so to prevent a cardiac arrest, the shock is timed to coincide with the pumping of the ventricles.

4. Arrhythmia
If the heart beats too fast, or at an irregular pace, it becomes unable to effectively pump blood around the body.

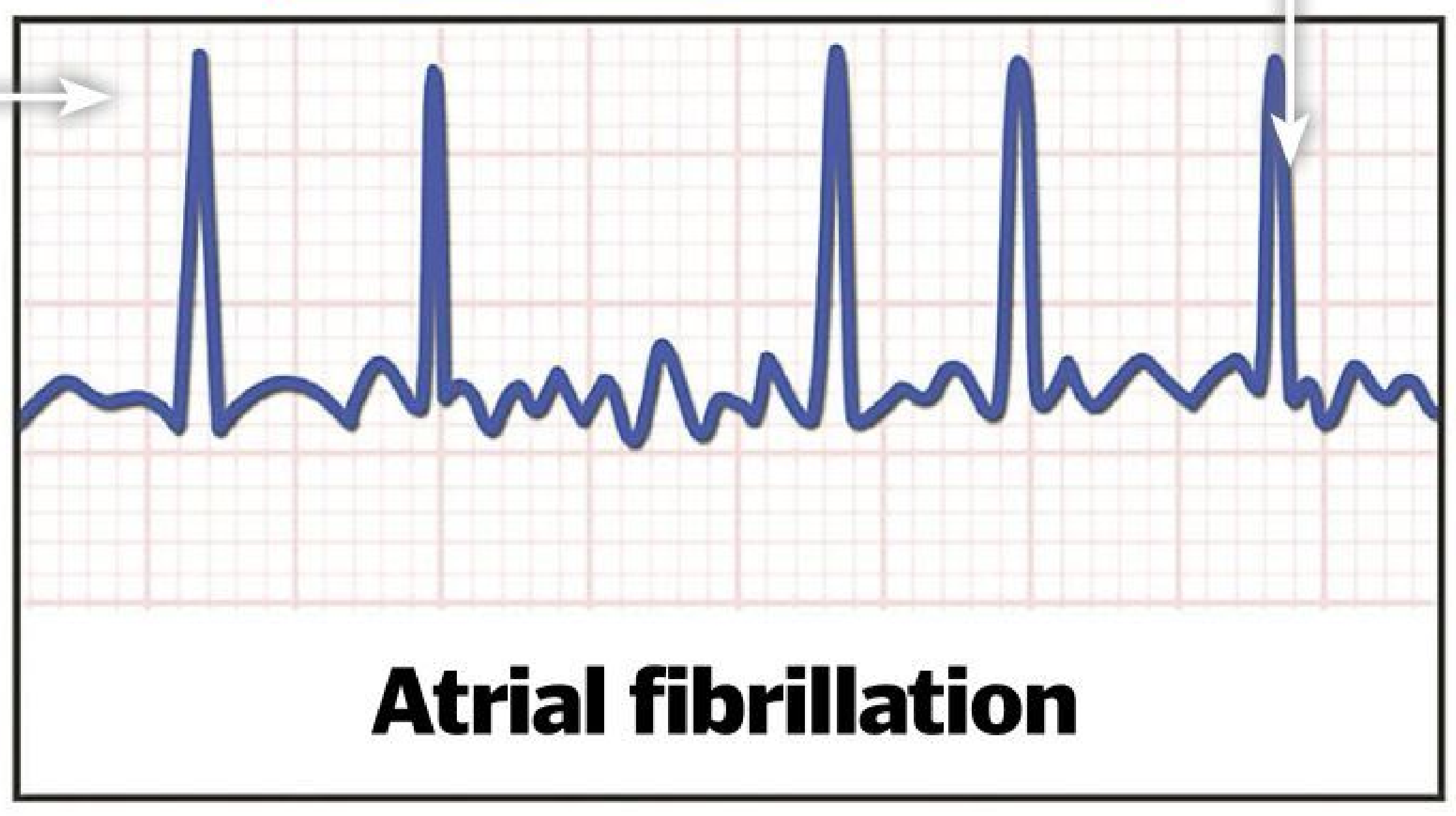
5. Electric shocks
Low-energy electric shocks are delivered to the heart through the electrodes.

6. Natural pacemaker
The heart has its own internal pacemaker known as the sinoatrial node. Delivering a small electric shock to this resynchronises the organ's natural electrical activity.

7. Cardioversion machine
The machine records the electrical activity of the heart and calculates the electric shocks required to restore the organ to its normal rhythm.

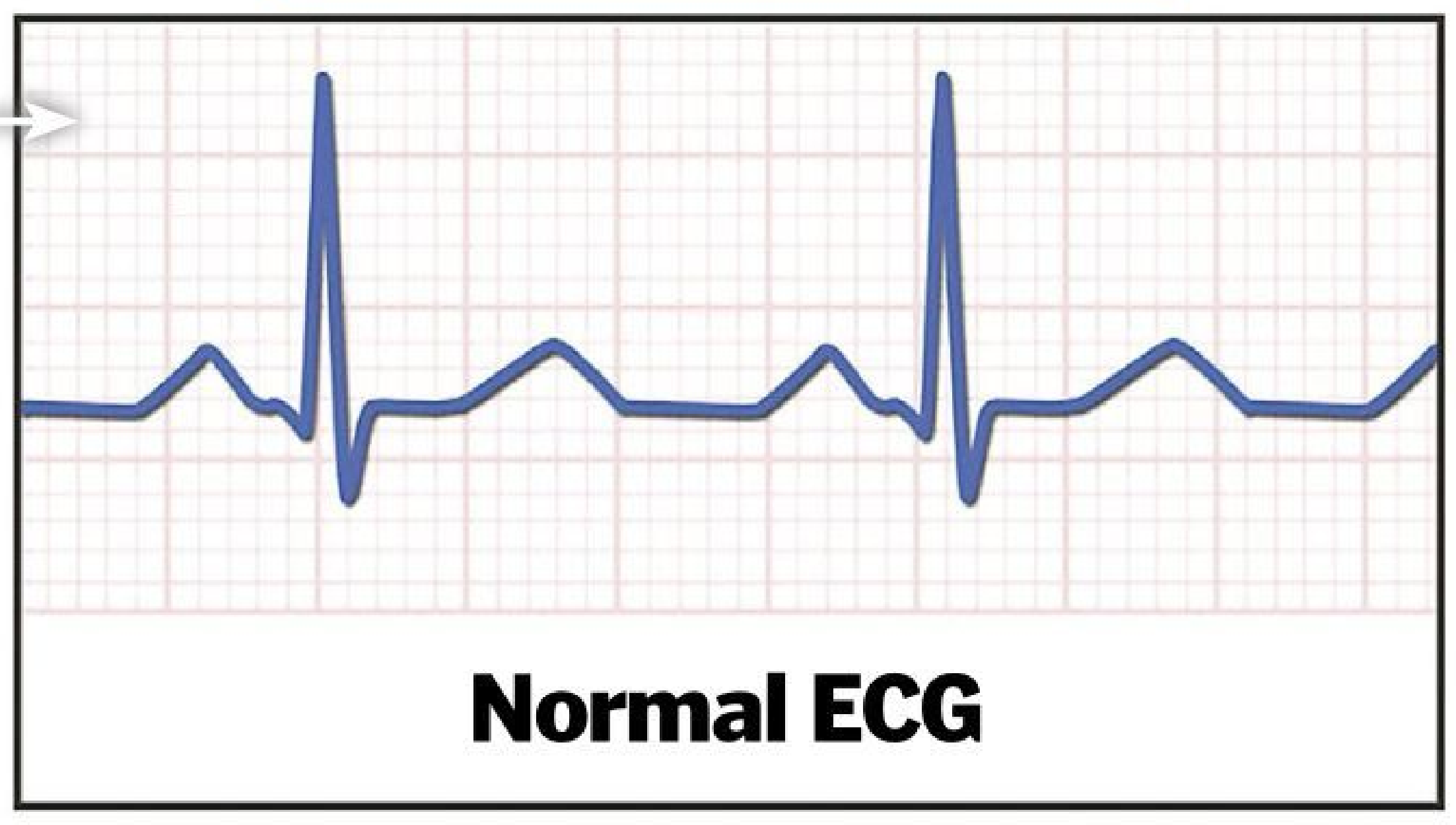
8. Low energy
Resetting an abnormal heart beat uses fairly low-energy shocks of just 50-200 joules.

BEFORE CARDIOVERSION



Atrial fibrillation

AFTER CARDIOVERSION



Normal ECG

Carpal tunnel syndrome

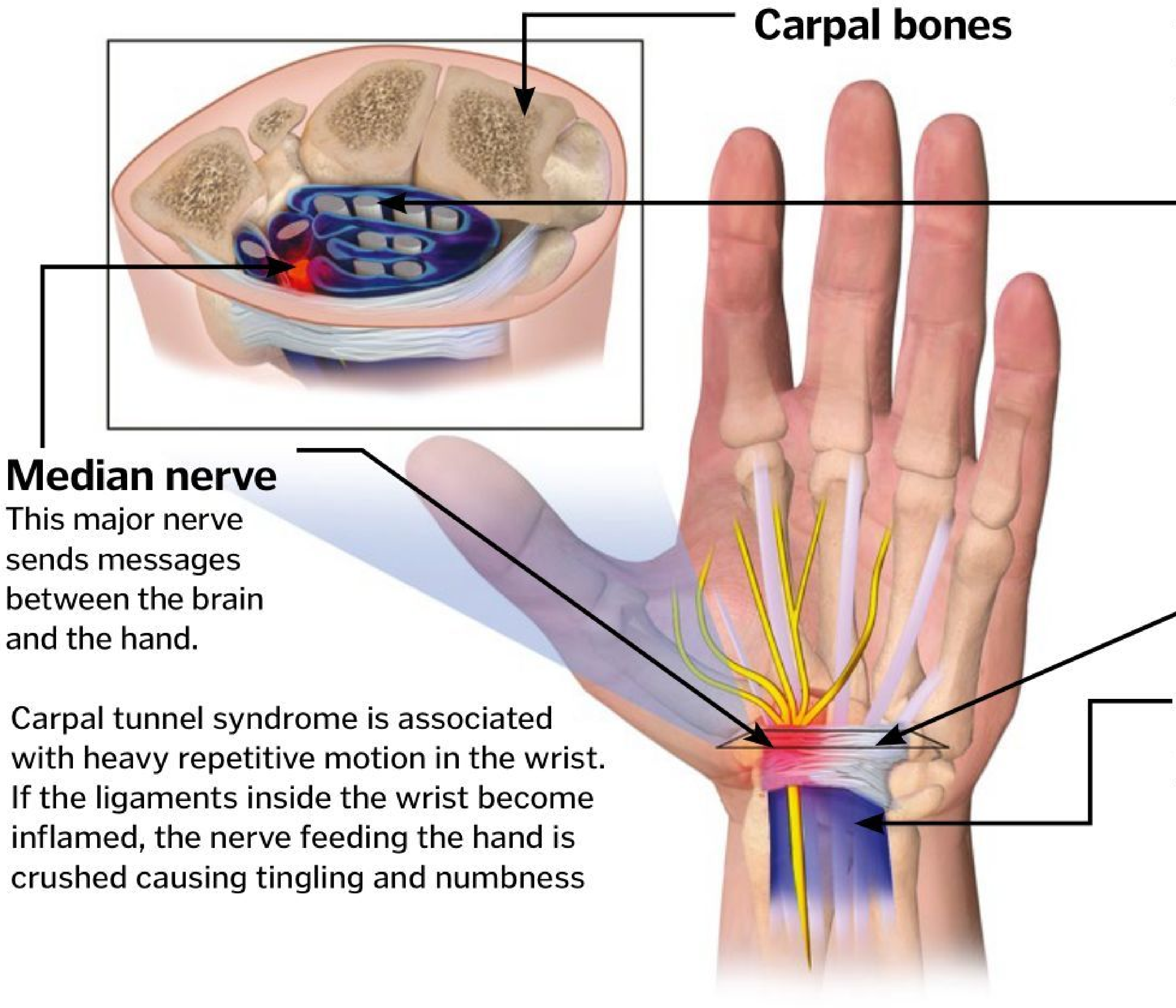
What is it about the anatomy of the wrist that leads to tingling and numbness?

The tendons and nerves of the human wrist travel through a narrow tunnel. The carpal bones form an arch, covered on the underside of the wrist by the tough carpal ligament.

This stiff tunnel has no room to expand, so if the ligaments become inflamed they can compress the median nerve. The median nerve carries sensory information from the thumb, index finger, middle finger and half of the ring finger, so when the nerve is compressed it can cause numbness, tingling and pins and needles in a specific pattern across the hand.

The pain is often most severe at night because the wrists are held flexed during sleep, compressing the nerve even further. Treatment can be as simple as immobilising the joint at night-time.

In more serious cases though, steroids may be used to reduce inflammation, and as a last resort, the carpal ligament can also be cut to release the pressure.



Carpal bones

Tendons
In the carpal tunnel, the tendons of the fingers surround the median nerve.

Carpal tunnel
A narrow passage made of small bones and a band of tissue that acts as a pulley for the tendons.

Median nerve
This major nerve sends messages between the brain and the hand.

Synovium
A membrane around the tendons secretes a lubricating fluid to keep joints flexible.

Carpal tunnel syndrome is associated with heavy repetitive motion in the wrist. If the ligaments inside the wrist become inflamed, the nerve feeding the hand is crushed causing tingling and numbness

Alamy

DID YOU KNOW? *Scientists have been searching for a human pheromone for decades, but are yet to find one*

What are pheromones?

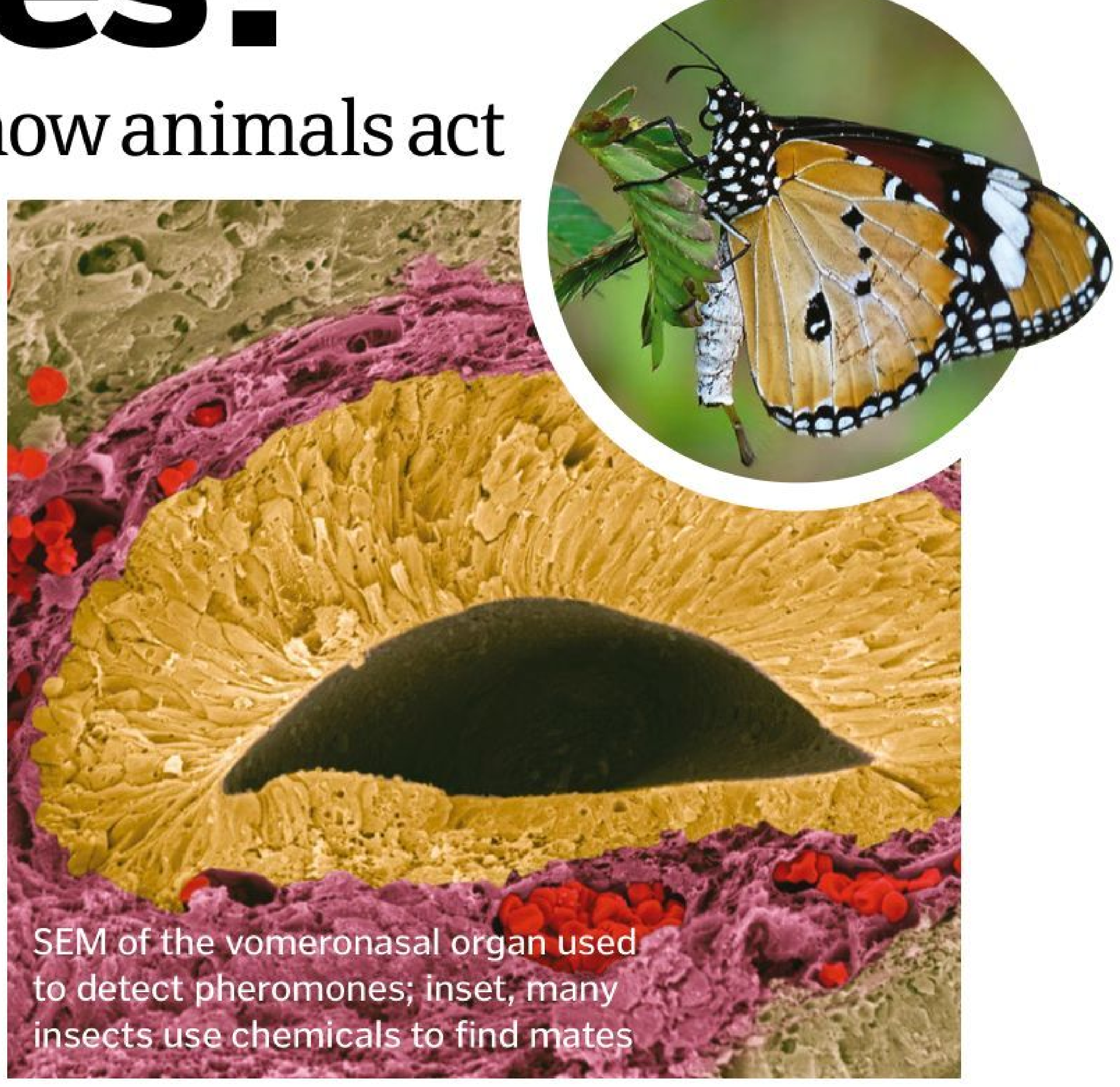
The science behind the chemicals which have a big effect on how animals act

Pheromones are a means of chemical communication between animals, allowing ants to form orderly lines in search of food, tigers to mark their territory and newborn rabbits to find their mother for milk.

Insects have multiple sense organs located on their antennae, while many animals have a specialist organ in the nose that is known as the vomeronasal organ (VNO). The VNO is linked by nerves to the hypothalamus – the region of the brain connecting the nervous system to the endocrine (hormone) system. Incoming signals can potentially affect a range of behaviours and physiologies, from aggression to reproduction.

Plants also use pheromones. For example, when an antelope eats the leaves of an acacia tree, it releases ethylene. This chemical alarm signal is effective for up to 45 metres (150 feet), and causes surrounding acacia trees to produce bitter-tasting tannin to discourage the antelope from grazing more. Some plants can also produce pheromones that alter insect behaviour.

Whether or not humans are sensitive to pheromones is debated. We don't always have a VNO, and our gene coding for the receptors look inactive. Still, in some animals normal nasal tissue can also detect pheromones, so there is a chance that humans might too.


SEM of the vomeronasal organ used to detect pheromones; inset, many insects use chemicals to find mates

What are pheromones used for in nature?

Raising the alarm

When certain species of insect or plant are under attack, they release alarm pheromones, alerting other members of their species to the danger. All individuals collectively respond to the alarm, either fleeing or mounting a unified defence.

Marking territory

Many animals use pheromones to mark the boundaries of their territory – a familiar trait of dogs. Some insects also use pheromones to signpost the location of their eggs, to prevent other females from laying in the same place.

Leaving a trail

A pheromone trail is the invisible road that guides ants. As more ants travel along the route, they add their own pheromones. Foraging ants will also leave trails to food but stop as the source is depleted, so the scent dissipates.

Recruitment

Bees scour large territories to find nectar, so in order to ensure they return to the hive, workers secrete a pheromone to direct them home. This powerful chemical messenger also attracts lone bees to join the colony as they fly past.

Finding a mate

Pheromones can be used to bring individuals together, whether for mating, defence or migration. Females often release pheromones to signal fertility, eg the female silkworm moth can lure a mate from up to 48 kilometres (30 miles) away!

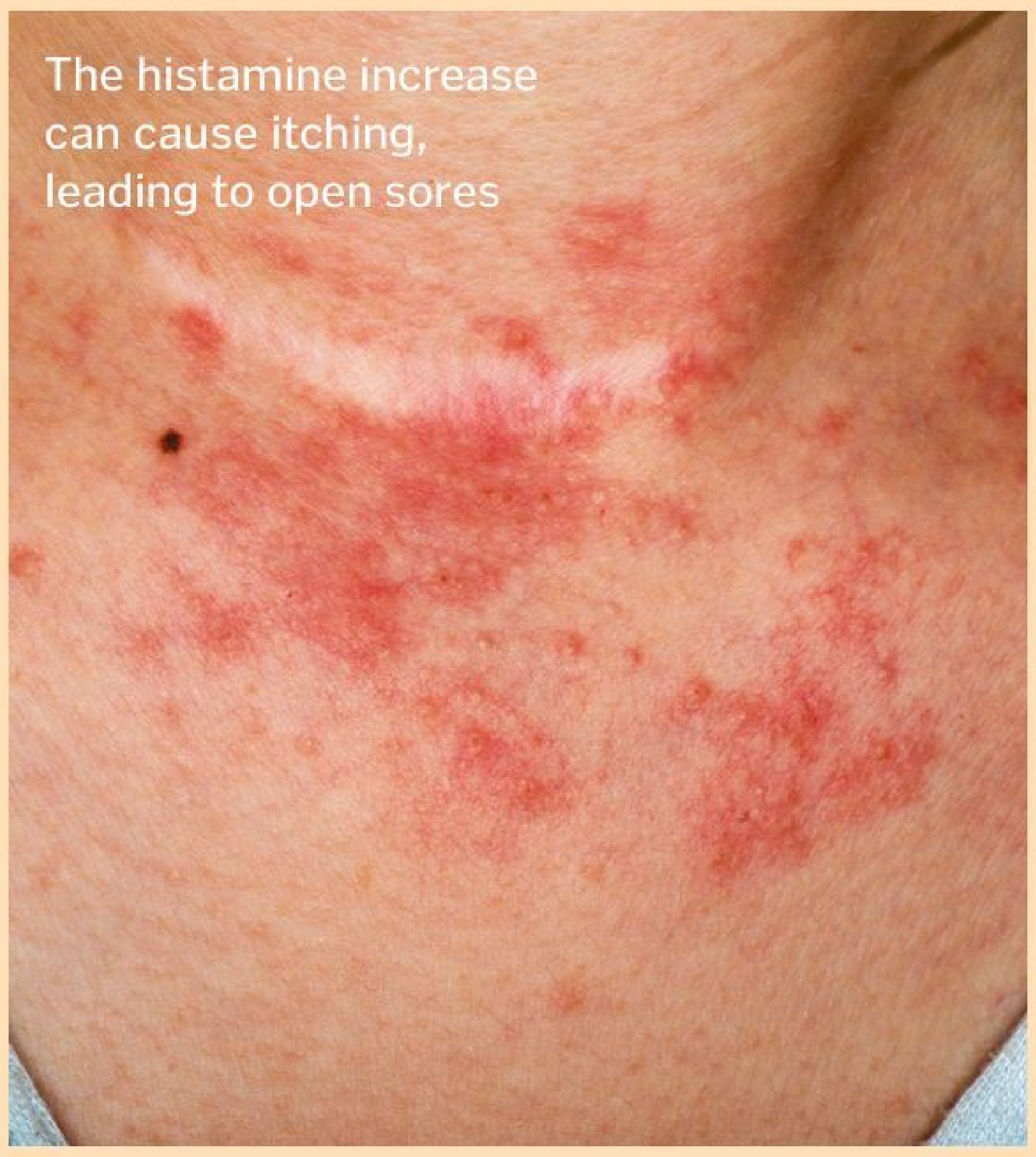
Eczema explained

What causes the skin to react to otherwise harmless material?

Eczema is a broad term for a range of skin conditions, but the most common form is atopic dermatitis. People with this condition have very reactive skin, which mounts an inflammatory response when in contact with irritants and allergens. Mast cells release histamine, which can lead to itching and scratching, forming sores open to infection.

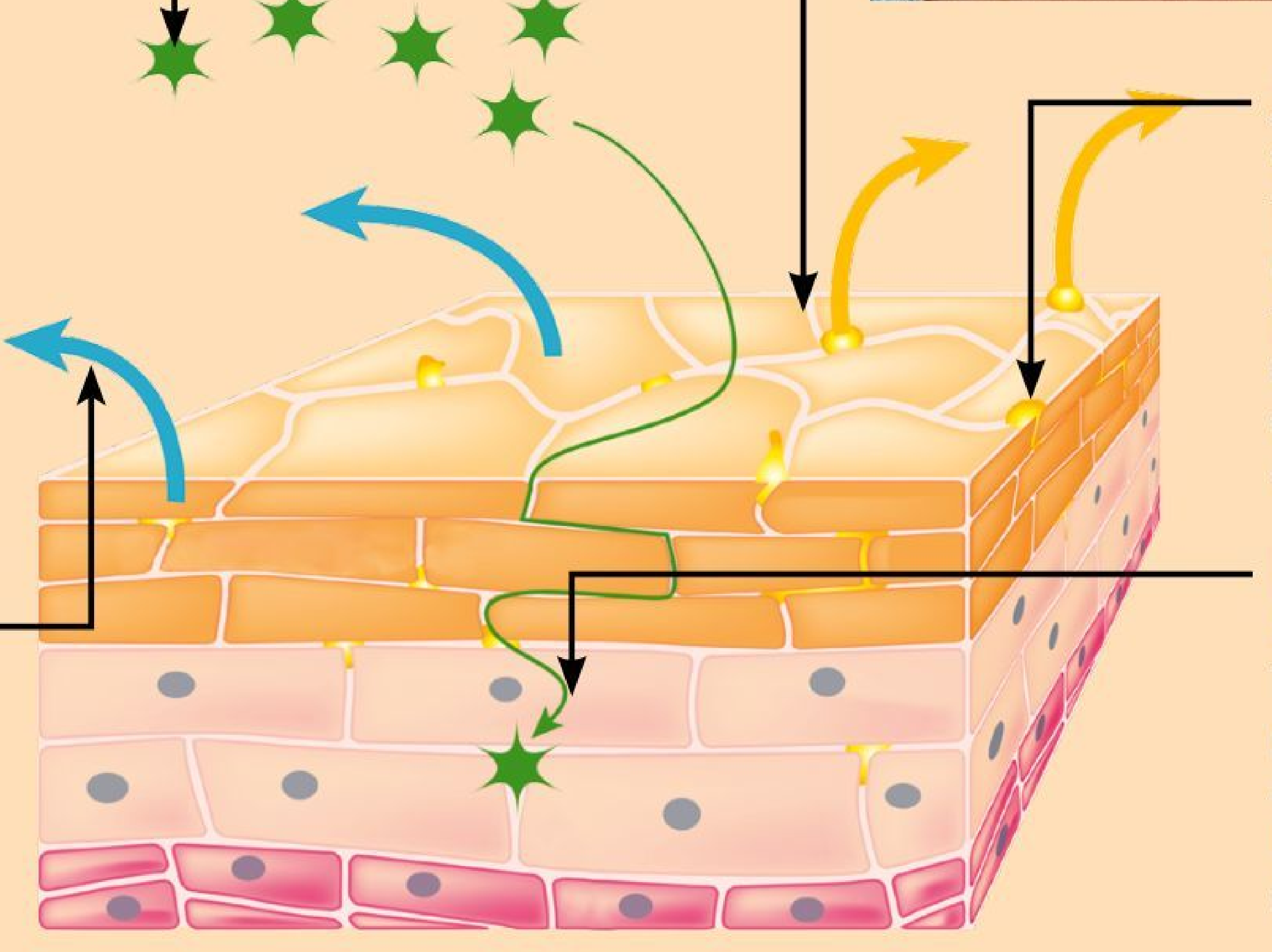
There is thought to be a genetic element to the disease and a gene involved in retaining water in the skin has been identified as a potential contributor, but there are many factors.

Eczema can be treated with steroids, which suppress immune system activity, dampening the inflammation so skin can heal. In serious cases, immunosuppressant drugs – used to prevent transplant rejection – can be used to weaken the immune system so it no longer causes inflammation in the skin.


The histamine increase can cause itching, leading to open sores

Under the skin

What happens inside the body when eczema flares up?



Ceramides
The membranes of skin cells contain waxy lipids to prevent moisture evaporation, but these are often deficient in eczema.

Allergen
Eczema is commonly triggered by the same things as many allergies – anything from pet hair to certain types of food.

Water loss
The skin is less able to retain water, leading to dryness and irritation.

Allergen entry route
The cells of the skin are normally tightly bound together to prevent contaminants from entering the body, but in eczema there are gaps.

Inflammatory response
The immune system produces a response to allergens beneath the skin, leading to redness, itching and inflammation.

© Alamy; J Kadavoor; Thinkstock

Inside the flu

We reveal how this common winter bug stays one step ahead of our immune system

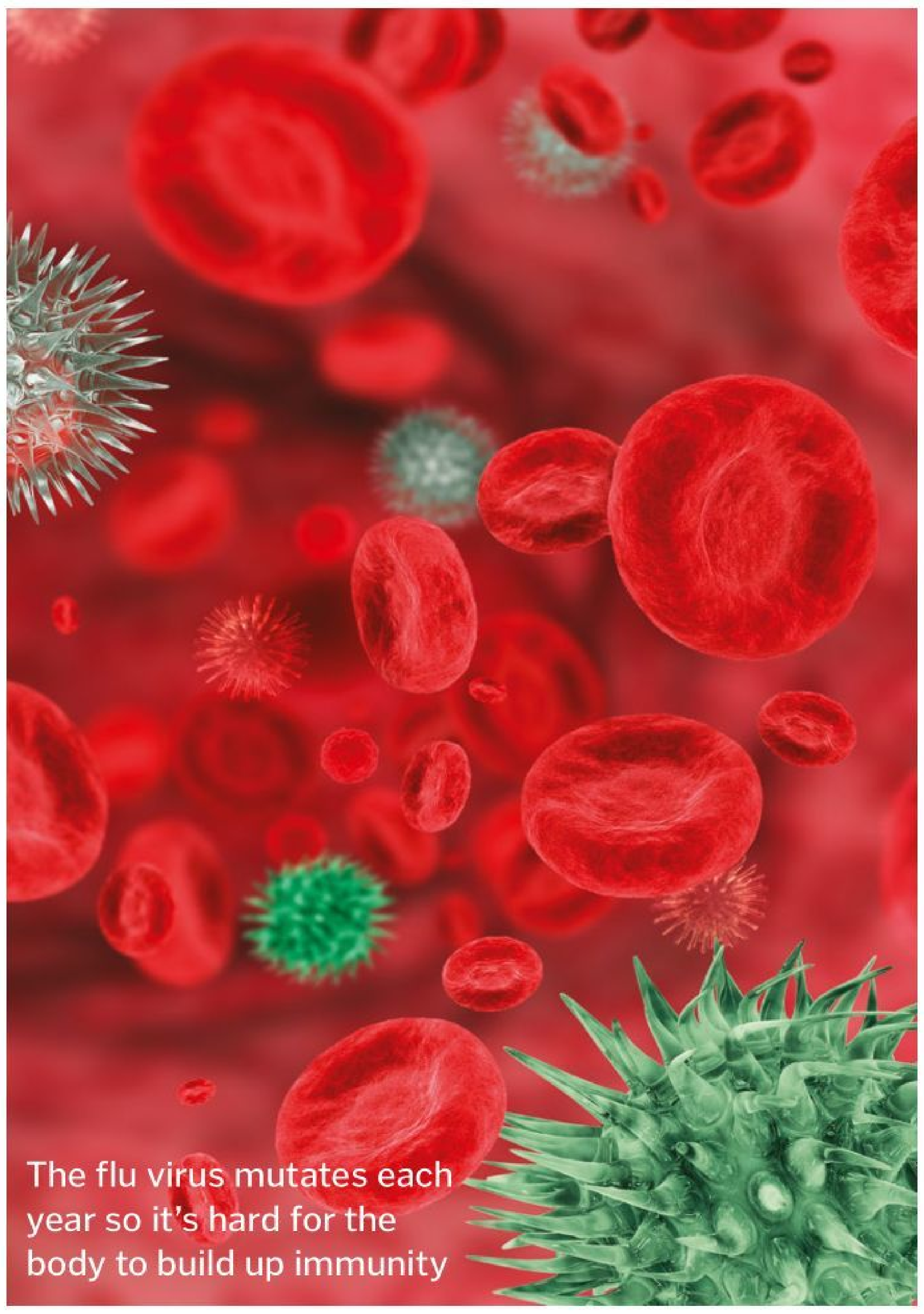
The influenza virus infects a staggering 5 million people worldwide every single year, travelling from person to person in airborne droplets, and causing chills, fever, sore throat, runny nose, headaches and muscle pain.

The flu virus changes gradually by a process known as antigenic drift. As the virus replicates, single nucleotide errors occur in the viral genome, causing minute changes to the proteins that coat the outside of the virus. The immune system recognises these proteins to detect and destroy the infection, so as they change, the ability of the body to recognise the virus decreases, preventing people from building up immunity.

Not only does the virus make continual, subtle changes to its genome and proteins, but it also occasionally develops huge mutations. If a host becomes infected by more than one strain of flu virus, and the two meet inside a single cell, there is a chance that their genomes will mix together, consequently producing new, mutant flu virus. This is a rather rare occurrence, but can form dangerous new strains of flu – the swine flu (H1N1) pandemic of 2009 was found to contain genetic information from four different viruses: one human, one avian and two swine influenza.

This is one of the reasons that a universal vaccine against all types of flu is such a challenge. Currently, a seasonal flu jab is developed every year, to match the flu that is circulating in the population. Each subsequent year, the virus has usually changed sufficiently that the vaccine is no longer effective.

However, research suggests that some cells of the immune system can recognise proteins from the core of the virus. These are essential to viral function, and mutate far more slowly, so developing a vaccine against these important proteins could help T-cells to develop long-term immunity to the bug.



The flu virus mutates each year so it's hard for the body to build up immunity

Get to know your ABCs…

Influenza A

The natural hosts of influenza A are wild water birds. Transfer to domestic poultry exposes humans to the virus and can result in cross-species infection. The H1N1 Spanish flu of 1918 and the H5N1 bird flu of 2004 were influenza A.

Influenza B

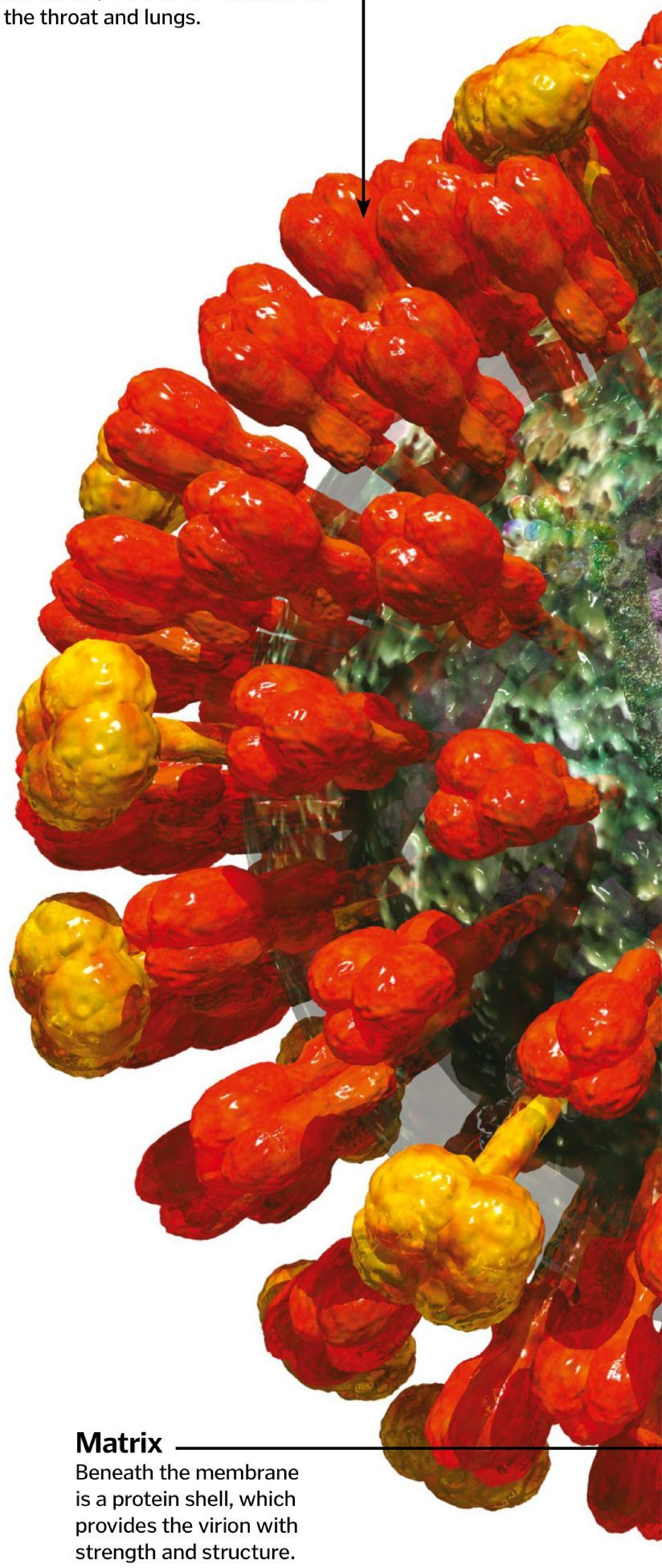
Influenza B prefers a human host and is less common. It mutates slowly, enabling most to build up immunity, but it doesn't last for ever. It rarely infects other species, preventing the creation of the new, mutant strains that cause pandemics.

Influenza C

This produces only mild disease, and most adults have been infected at some point in their life. It infects humans and pigs, but is far less common than influenza A and B. It can cause local epidemics, but does not lead to pandemic flu.

The virus in focus

Take a closer look at the anatomy that makes up a single flu virion

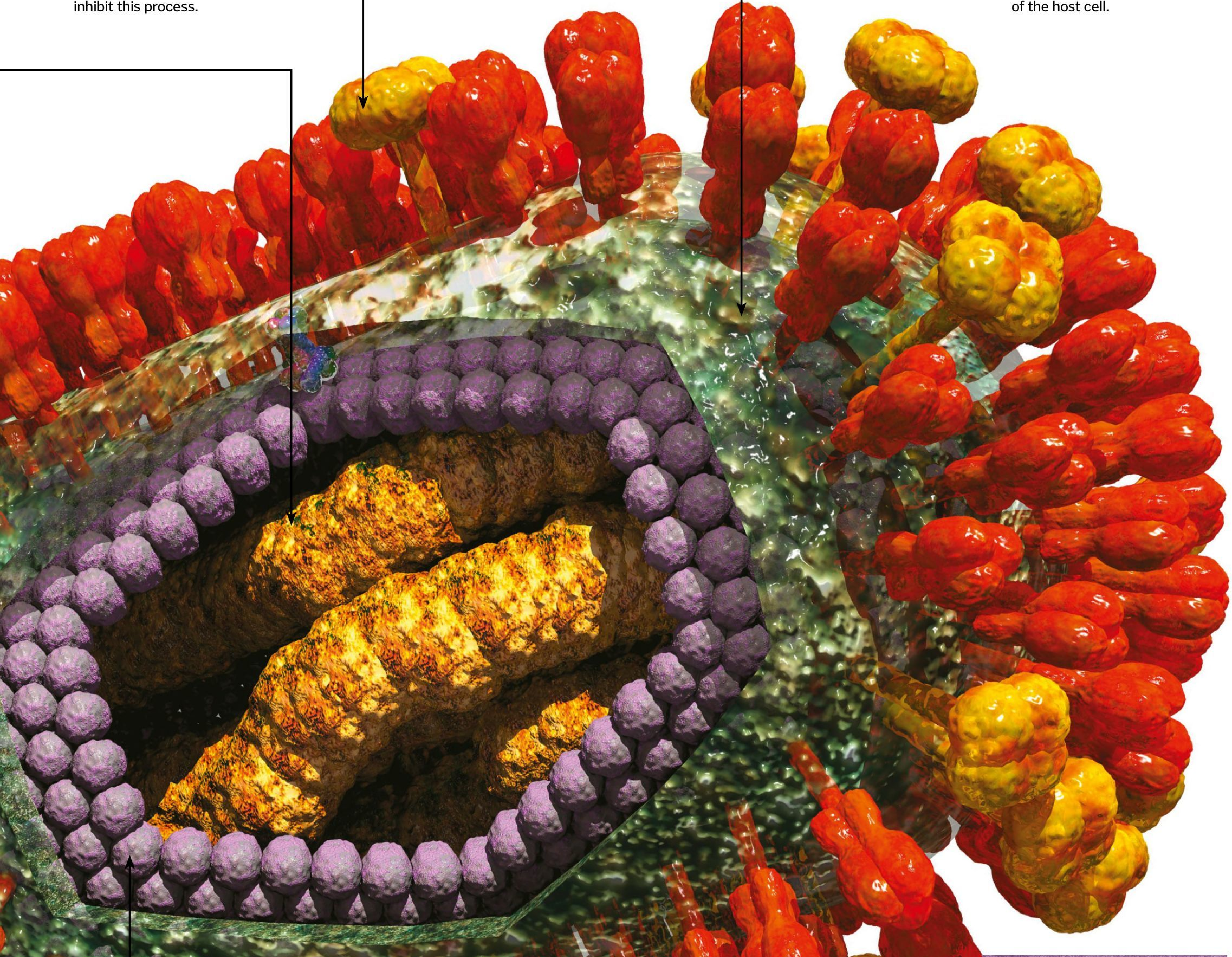


RNA
The genetic material of the flu virus is stored on several strands of ribonucleic acid (RNA).

Haemagglutinin
Spiky protein haemagglutinin coats the outside of the virion, allowing it to stick to, enter and infect cells of the throat and lungs.

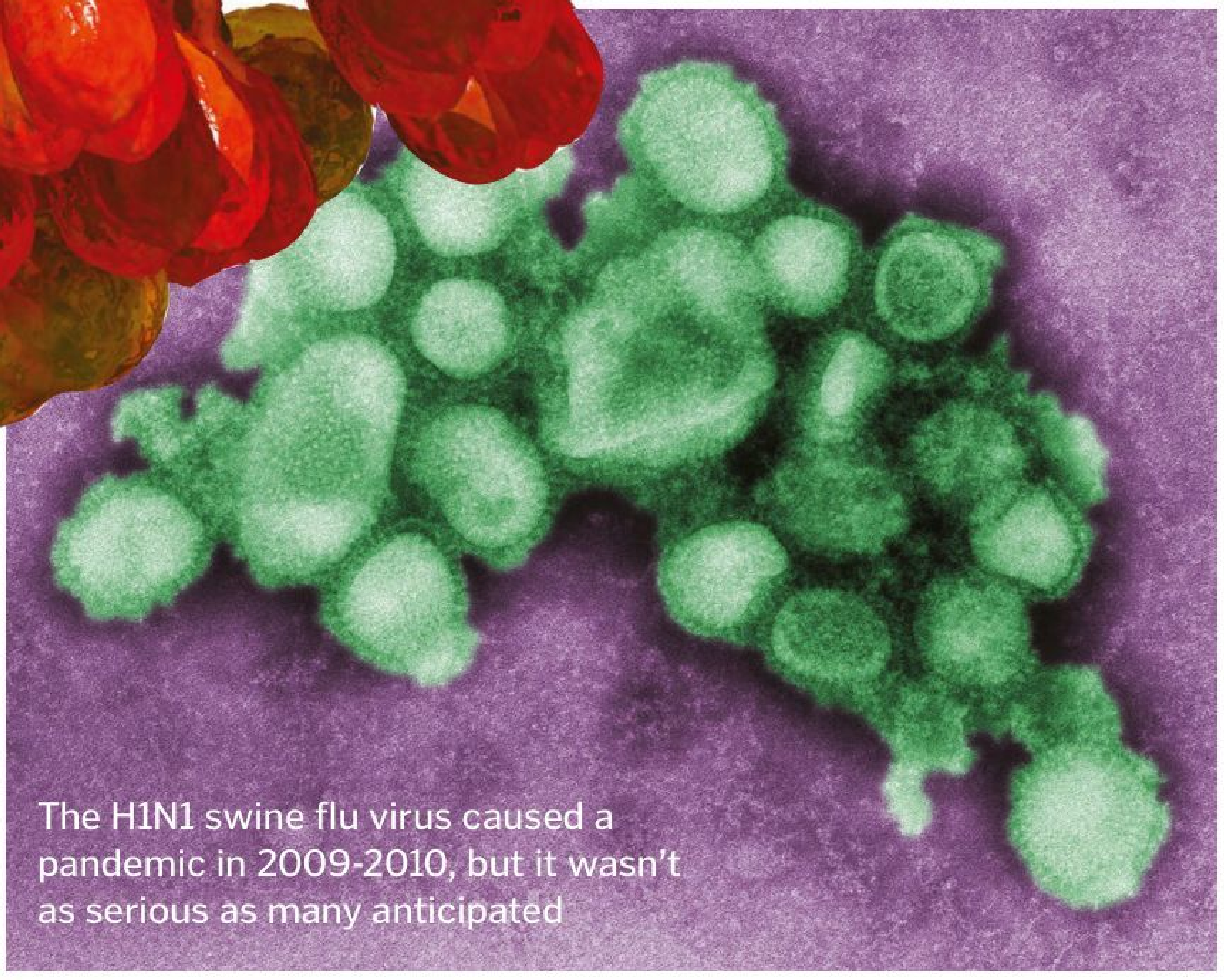
Matrix
Beneath the membrane is a protein shell, which provides the virion with strength and structure.

DID YOU KNOW? *Influenza A viruses are named after the two major proteins that cover their outer membrane*



Neuraminidase
This surface protein is an enzyme, which helps the virus to eat through cell defences and breach the cell membrane. Drugs like Relenza and Tamiflu inhibit this process.

Lipid bilayer
The outer layer of the virion is a lipid membrane. It is not produced by the virus, but is stolen from the membrane of the host cell.

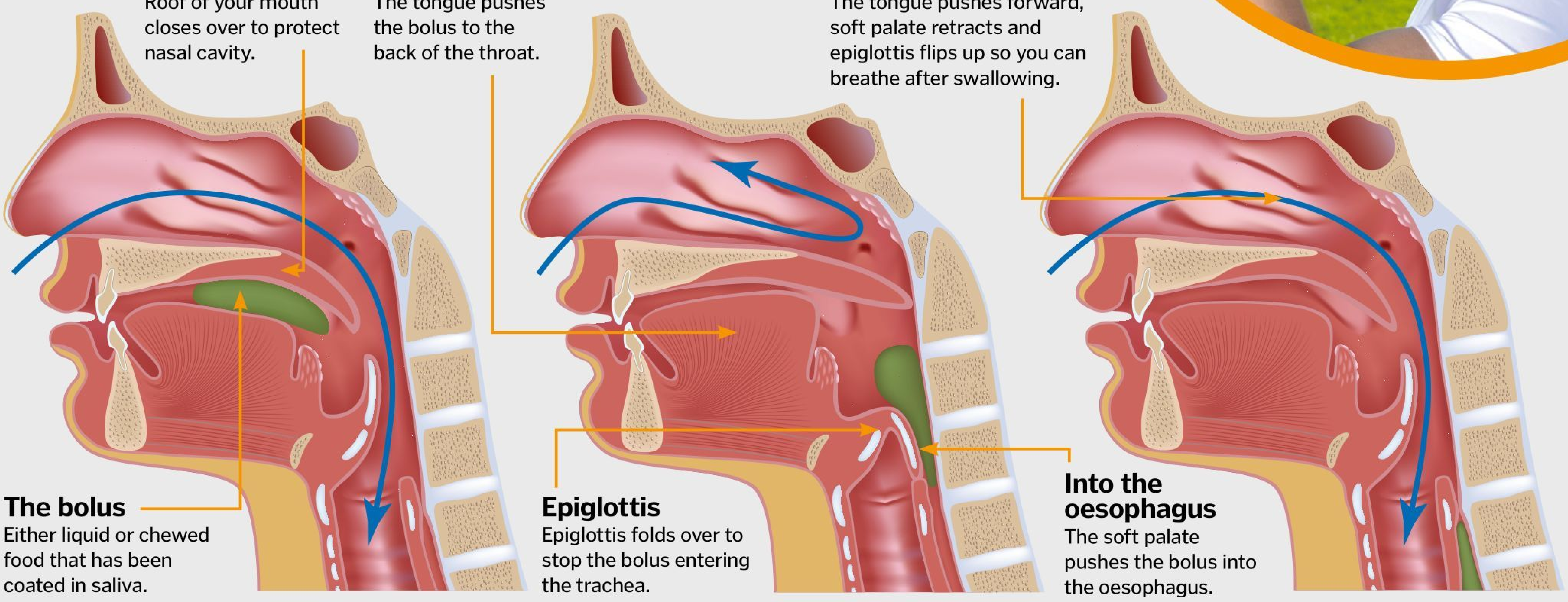


The H1N1 swine flu virus caused a pandemic in 2009-2010, but it wasn't as serious as many anticipated

© SPL; Thinkstock

How we swallow

The process of getting your food from mouth to stomach



Soft palate
Roof of your mouth closes over to protect nasal cavity.

Tongue
The tongue pushes the bolus to the back of the throat.

Cycle ends
The tongue pushes forward, soft palate retracts and epiglottis flips up so you can breathe after swallowing.

The bolus
Either liquid or chewed food that has been coated in saliva.

Epiglottis
Epiglottis folds over to stop the bolus entering the trachea.

Into the oesophagus
The soft palate pushes the bolus into the oesophagus.

Swallowing is a whirlwind of action that all happens in a rapid but controlled order. Your tongue pushes the chewed food (bolus) to the back of your throat and the muscle on the roof of your mouth – your soft palate – pushes the food or drink down into the pharynx. The bolus is prevented from going down the windpipe thanks to the epiglottis, a small flap of skin folding over the larynx. This forces what you are swallowing to head down the oesophagus. All of this happens in less than a second.

However, sometimes things do go wrong. We've all experienced food or drink 'going down the wrong pipe.' This is called pulmonary aspiration and occurs when the epiglottis hasn't covered the trachea in time and the bolus has entered your breathing tube. This uncomfortable sensation generally ends with you coughing and spluttering until it is cleared.

Why do we get drunk?

It's the drug of choice for many, but just how does alcohol get you drunk, and why do we suffer from the side effects?

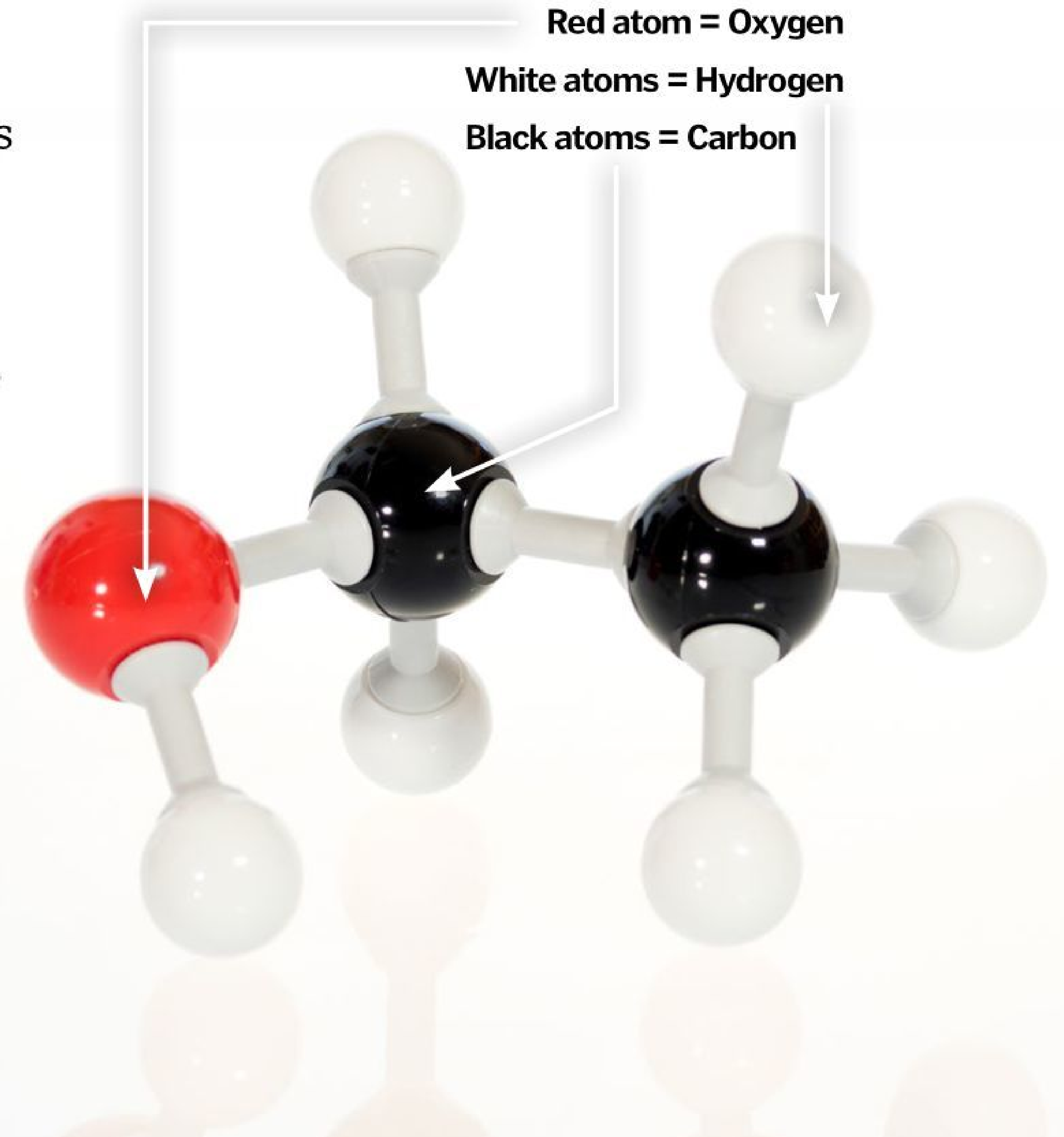
There are actually many kinds of alcohol in the chemical world, but the one we drink the most is ethanol. It's the particular shape of an ethanol molecule that gives a glass of beer or a shot of the hard stuff its specific effects on the human brain. The molecule is very tiny, made up of just two carbon atoms, six hydrogen atoms, and one oxygen atom. Ethanol is water soluble, which means it enters the blood stream readily, there to be carried quickly to all parts of the body (most notably the liver and the brain). It's also fat soluble; like an all-access pass through various cell membranes and other places that are normally off limits.

A certain portion of the ethanol you drink passes through your stomach to your small intestine, is absorbed into your bloodstream and carried to your brain. That's what we're really concerned with. Research has not conclusively determined exactly how ethanol accomplishes all of its various effects in the brain, but there are some well-supported theories. The slow reactions, slurred speech and memory loss of a drunk are probably caused by ethanol attaching to glutamate receptors in your brain's neural circuitry. These receptors normally receive chemical signals from other parts of the brain, but instead they get an ethanol molecule. This disrupts the flow of signals and generally slows the whole brain down.

Ethanol also binds to GABA (gamma-aminobutyric acid) receptors, which normally serve to slow down brain activity. Unlike glutamate receptors, ethanol actually makes GABA receptors more receptive, causing the brain to slow down even more. But alcohol isn't simply a depressant, because it also stimulates the production of dopamine and endorphins, chemicals that produce feelings of pleasure. Research hasn't yet revealed the exact mechanism involved, but it may be similar to the way ethanol stimulates the GABA receptors.

Ethanol molecule

The particular shape of an ethanol molecule makes it ideally suited to getting humans drunk. Slight differences in the charge at each end of the molecule make it both water and fat soluble.



Red atom = Oxygen
White atoms = Hydrogen
Black atoms = Carbon

DID YOU KNOW? *We can burn 10-40 calories a day by laughing for just 15 minutes*

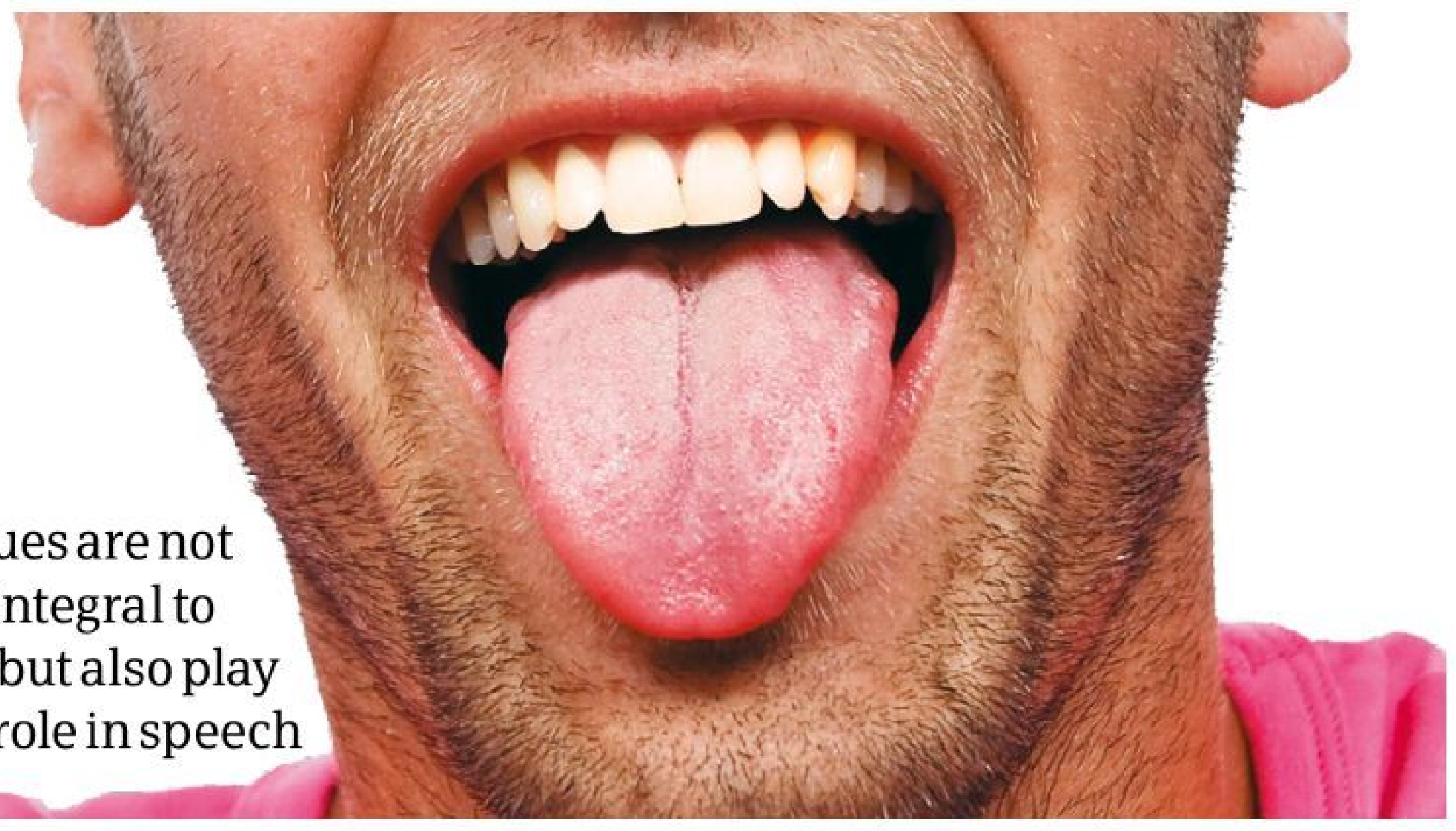
The human tongue

A versatile organ that allows you to both taste and talk

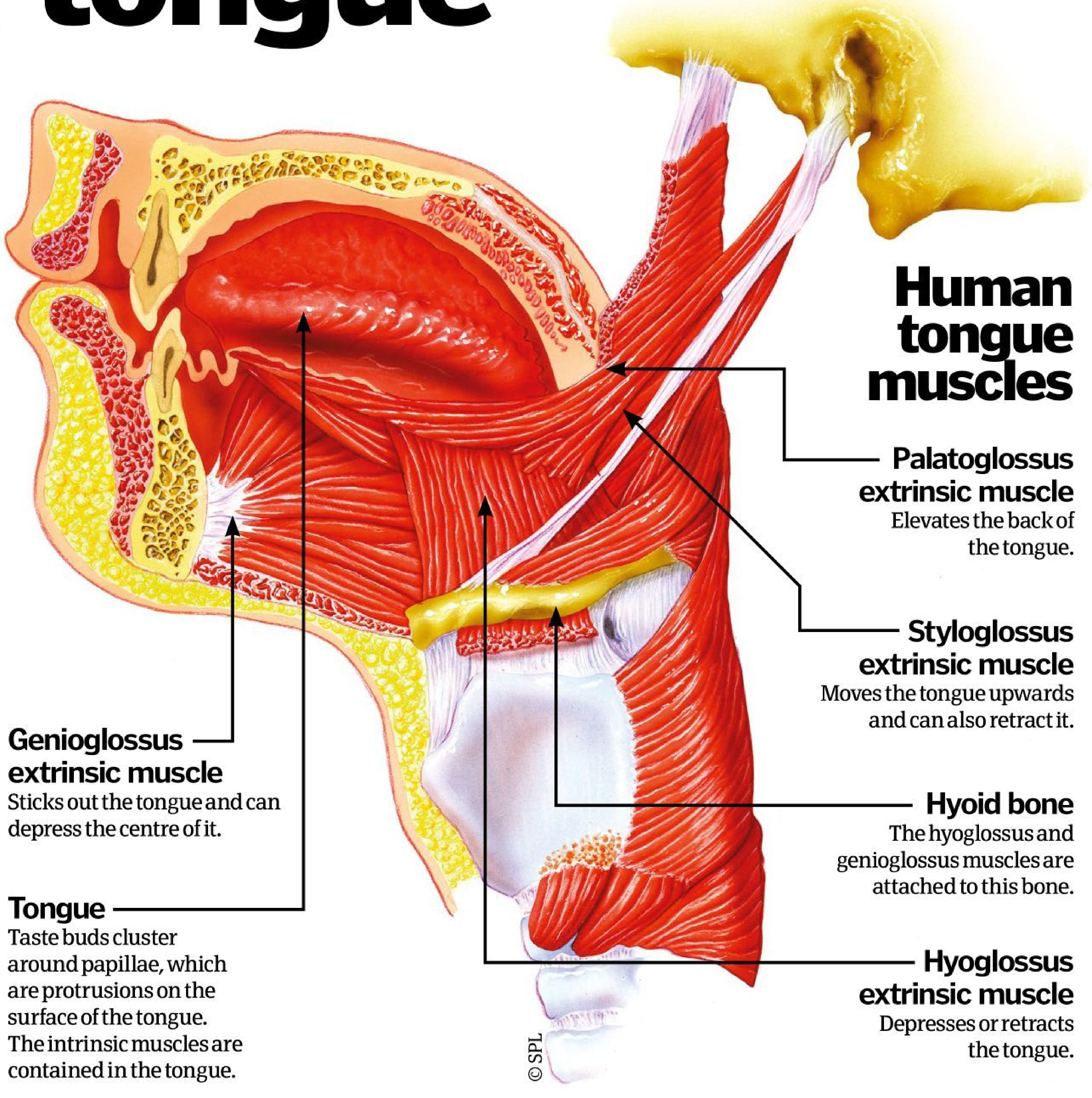
On our tongues, we have up to 10,000 taste buds that can distinguish between sweet, sour, bitter, salty and savoury flavours. As food is dissolved by our saliva, it meets taste receptor cells inside the taste buds that, when stimulated, send signals to the cerebral cortex. Receptors in the tongue also respond to other stimuli like pain, temperature and pressure.

The tongue consists of eight muscles: four of them are extrinsic muscles that are anchored to bone and change the position of the tongue, and four are intrinsic muscles that are not anchored to bone and change the shape of the organ.

Besides guiding food as we chew and swallow it, these muscles also give us the ability to speak. In combination with the mouth, jaws and cheeks the tongue moves to articulate sounds that emanate from the vocal folds of the larynx.



Tongues are not only integral to taste but also play a big role in speech



Human tongue muscles

Palatoglossus extrinsic muscle
Elevates the back of the tongue.

Styloglossus extrinsic muscle
Moves the tongue upwards and can also retract it.

Hyoid bone
The hyoglossus and genioglossus muscles are attached to this bone.

Hyoglossus extrinsic muscle
Depresses or retracts the tongue.

Genioglossus extrinsic muscle
Sticks out the tongue and can depress the centre of it.

Tongue
Taste buds cluster around papillae, which are protrusions on the surface of the tongue. The intrinsic muscles are contained in the tongue.

© SPL

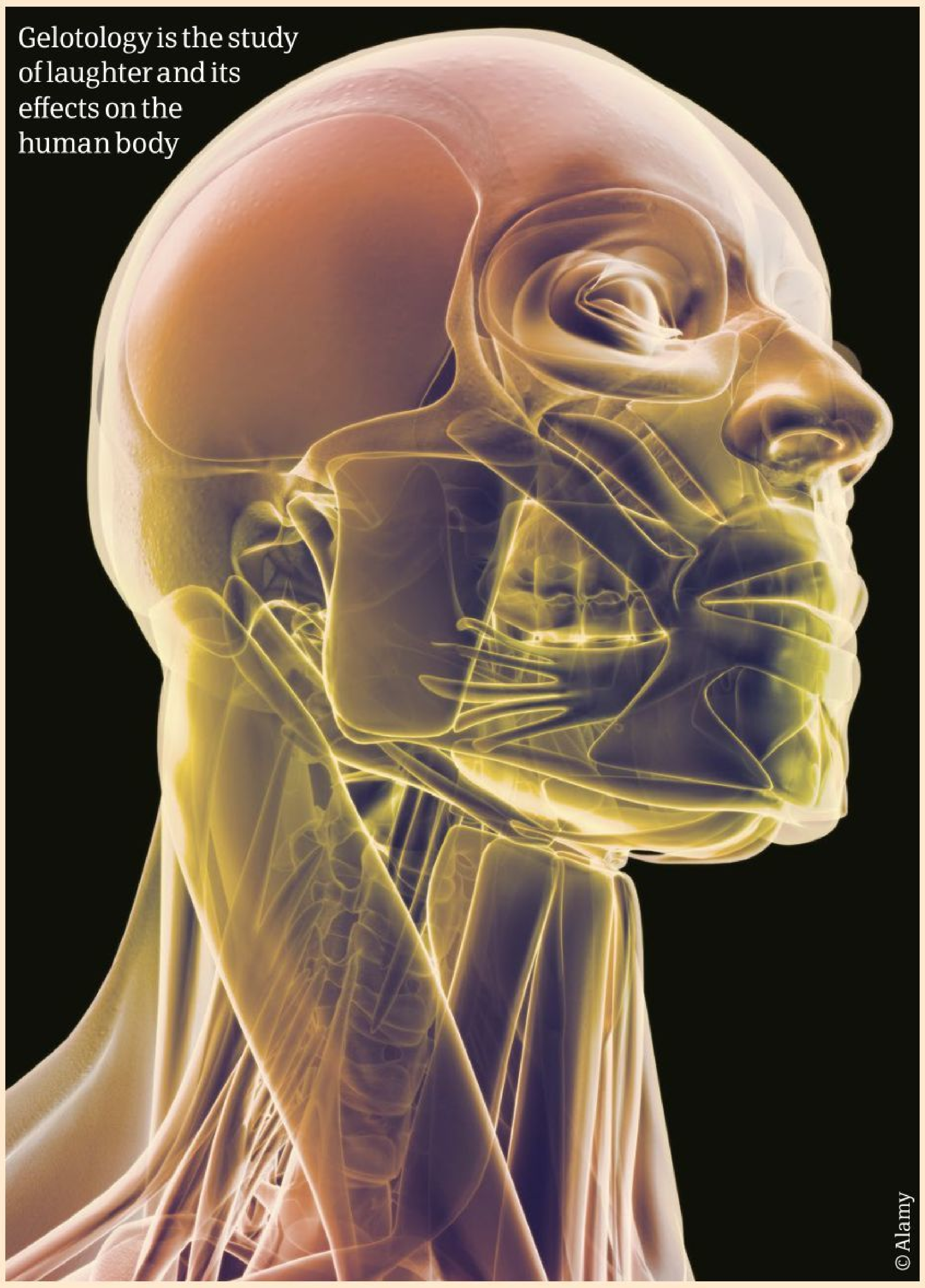
How do we laugh?

Which muscles react when we find something funny and why is laughter so hard to fake?

Laughing can sometimes be completely involuntary and involves a complex series of muscles, which is why it's so difficult to fake and also why an active effort is required to suppress laughter.

In the face, the zygomaticus major and minor anchor at the cheekbones and stretch down towards the jaw to pull the facial expression upward; on top of this, the zygomaticus major also pulls the upper lip upward and outward. The sound of our laugh is produced by the same mechanisms which are used for coughing and speaking: namely, the lungs and the larynx. When we're breathing normally, air from the lungs passes freely through the completely open vocal cords in the larynx. When they close, air cannot pass, however when they're partially open, they generate some form of sound. Laughter is the result when we exhale while the vocal cords close, with the respiratory muscles periodically activating to produce the characteristic rhythmic sound of laughing.

The risorius muscle is used to smile, but affects a smaller portion of the face and is easier to control than the zygomatic muscles. As a result, the risorius is more often used to feign amusement, hence why fake laughter is easy to detect.



Gelotology is the study of laughter and its effects on the human body

© Alamy

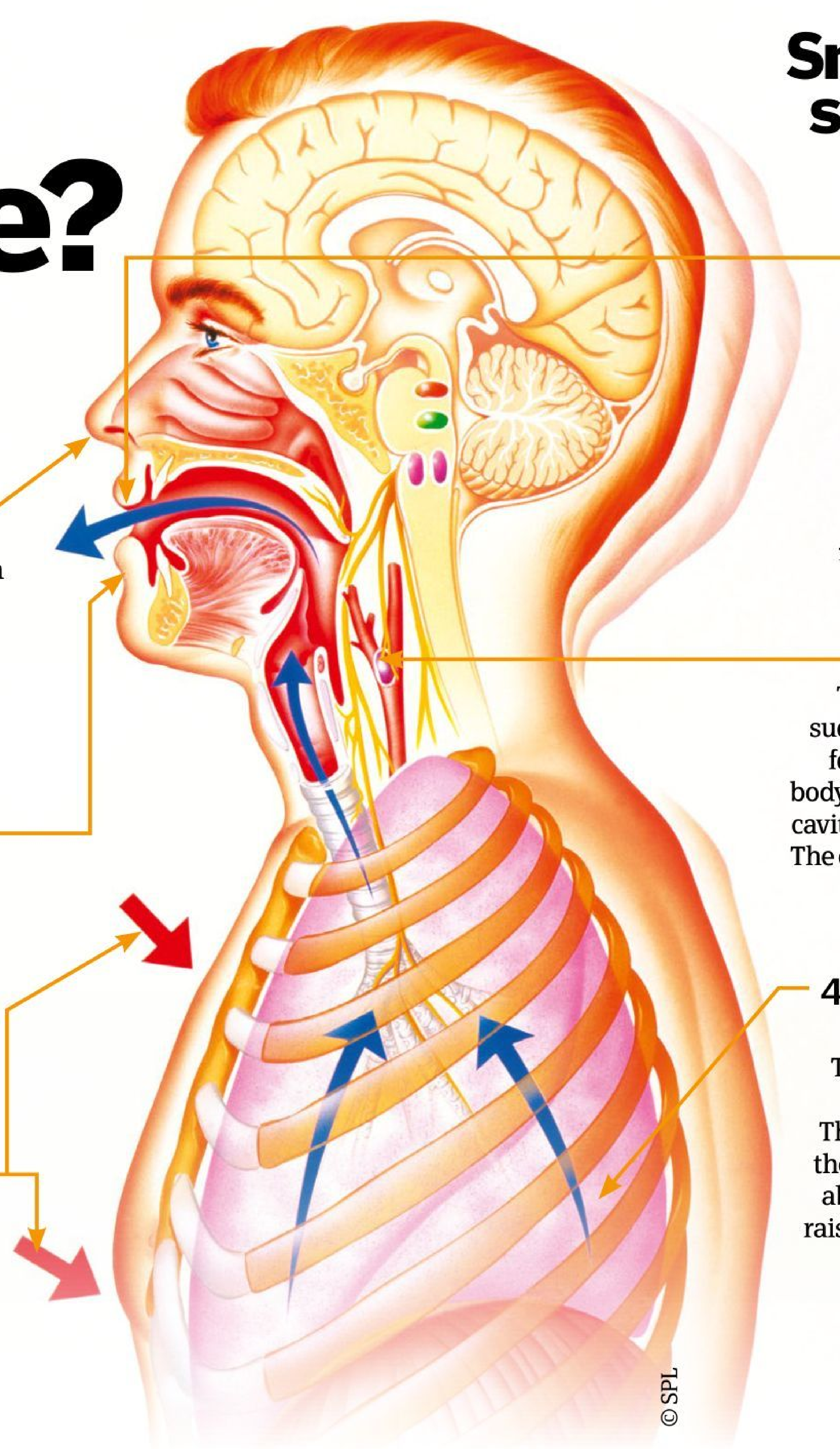
What happens when you sneeze?

How does this automatic reflex expel unwanted irritants from the body?

When we breathe in, the inhaled air can contain dust, chemicals and other irritants that can be harmful to the body, particularly to organs in the respiratory system like the lungs. While the tiny hairs inside the nostrils (cilia) trap many of these particles, some will often get through. To help you out, your body reacts to try and forcibly expel the offending particles via the sneeze reflex arc.

There are a number of other reasons why we sneeze, including to clear the nasal passages when you have a cold, to expel allergens if you are allergic to something, and interestingly even bright sunlight can cause some people to sneeze; this is specifically called photic sneezing.

When a stimuli is detected by the nerve endings in the nose, impulses are sent to the brain, which initiates a chain of physiological events that enable the body to rid itself of the unwelcome item.



© SPL

Sneezing step-by-step

1. Irritation
Prior to irritation, the diaphragm muscles are relaxed. When an irritant enters the body, nerve endings in the lining of the nose signal to the brain.

2. Muscles contract
The brain tells the respiratory muscles – including throat, chest and diaphragm – to contract.

3. Intake of breath
Contraction of the diaphragm causes a sharp intake of breath.

4. Air pressure rises
The brain signals to the throat to close. This, combined with the contraction of the abdominal muscles, raises the air pressure inside the lungs.

5. Sneeze
The throat reopens suddenly, explosively forcing air out of the body, making the chest cavity contract sharply. The diaphragm relaxes once again.

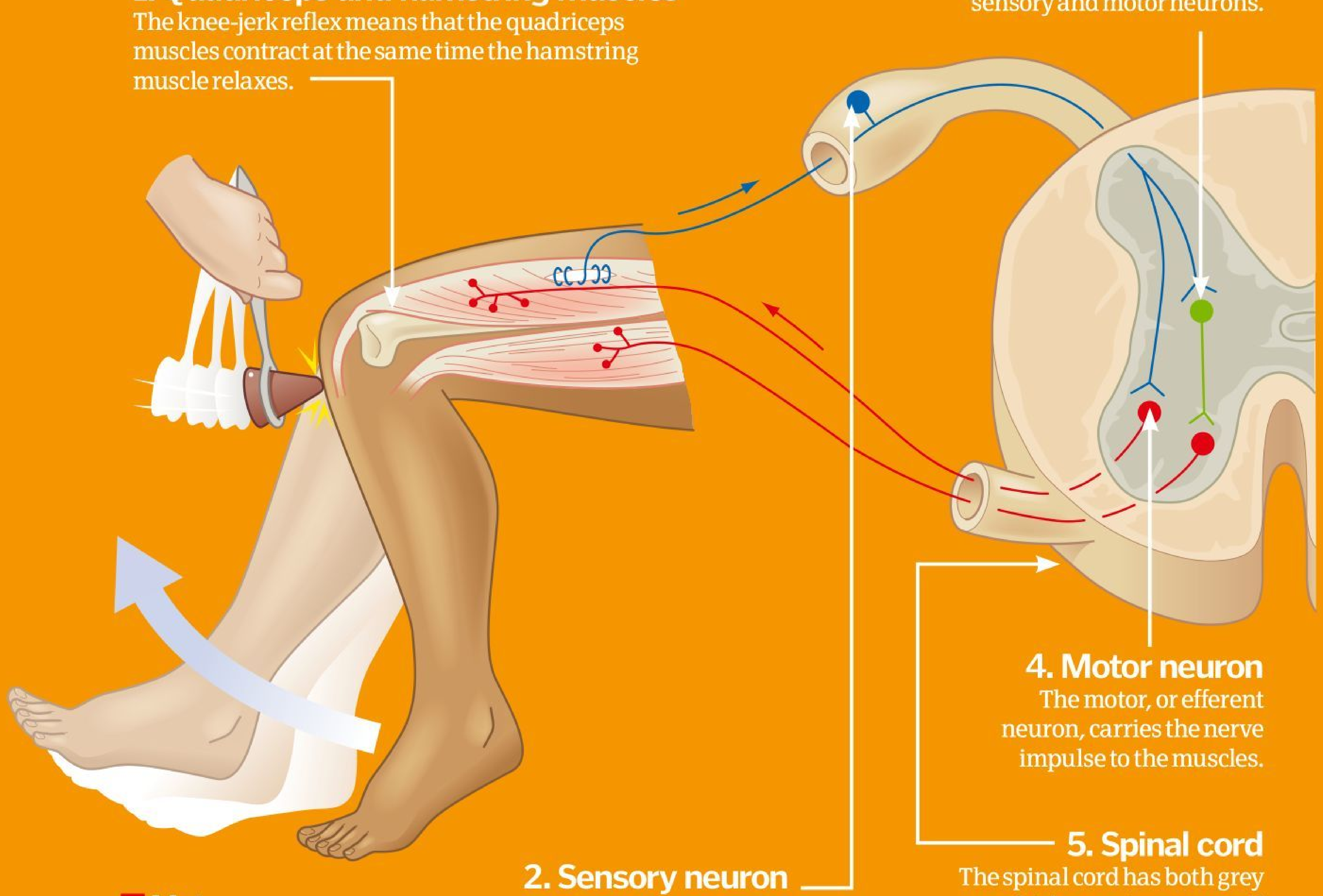
6. Mucus
Together with the offending irritant, saliva and mucus from inside the mouth and nasal cavity are also expelled from the body at up to 160km/h (100mph).

Knee-jerk reactions explained

Why does your leg kick out when the doctor taps just below your knee?

Doctors often test the knee-jerk, or patellar reflex, to look for potential neurological problems. Lightly tapping your patellar tendon just below the kneecap stretches the femoral nerve located in your thigh, which in turn causes your thigh muscle (quadriceps) to contract and the lower leg to extend. When struck, impulses travel along a pathway in the dorsal root ganglion, a bundle of nerves in the L4 level of the spinal cord. Reflex actions are performed independently of the brain. This allows them to happen almost instantaneously – in about 50 milliseconds in the case of the knee-jerk reflex. This reflex helps you to maintain balance and posture when you walk, without having to think about every step you take.

The knee-jerk step-by-step



1. Quadriceps and hamstring muscles
The knee-jerk reflex means that the quadriceps muscles contract at the same time the hamstring muscle relaxes.

2. Sensory neuron
The sensory, or afferent neuron, receives an impulse from the femoral nerve.

3. Interneuron
The interneuron provides a connection between the sensory and motor neurons.

4. Motor neuron
The motor, or efferent neuron, carries the nerve impulse to the muscles.

5. Spinal cord
The spinal cord has both grey matter, which contains nerve cell bodies, and white matter, which contains the nerve fibres.

🟥 Motor neuron
🟦 Sensory neuron
🟩 Interneuron

DID YOU KNOW? *What is sensed is referred to as a 'sense datum', while sensation refers to a mental process*

Sensory receptors allow us to feel physical contact

How do we touch and feel?

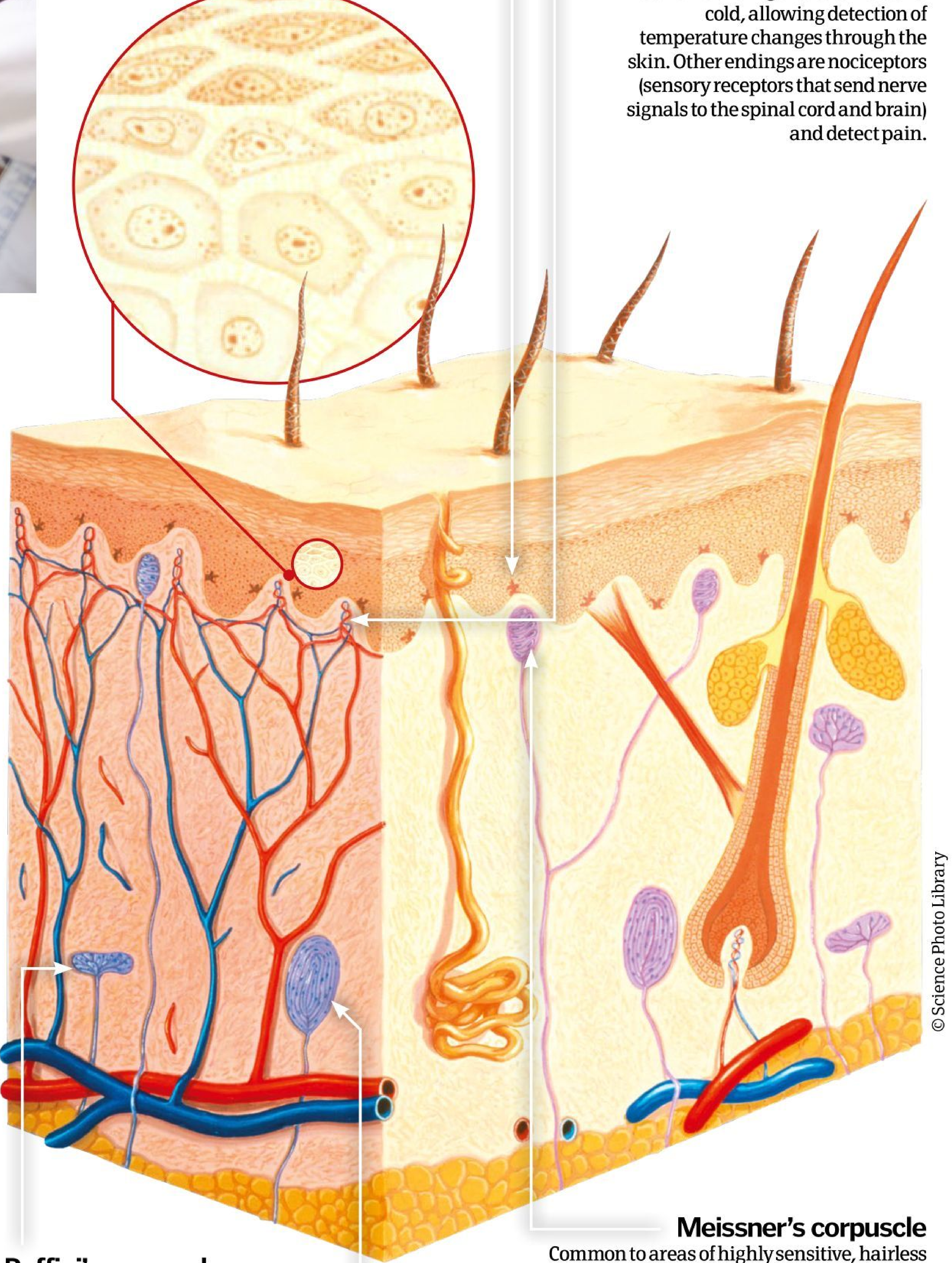
Sensation is the act of detecting different aspects of touch. But how does it work?

The skin is the largest sense organ of the human body. By sending nerve impulses (signals) to the sensory area of the brain, the skin can respond quickly and accurately to external stimuli in the detection of pain, texture and temperature, among others. This enables us to experience sensations, including the many 'sense datums' (a term coined by eminent scholar Bertrand Russell to separate the process of sensing to that which is being sensed), involved with touch.

This is achieved through a collection of sensory receptors within the skin, most of which are mechanoreceptors, sensors that specifically respond to mechanical pressure, distortion and vibration. In addition to mechanoreceptors, human skin also packs thermoreceptors for the detection of changes in temperature and, importantly, pain-detecting nociceptors. The positioning of each type of sensor in the dermis (one of the skin's three main layers) is directly linked to its role, with large receptors designed to detect pressure changes located deep within, while smaller sensors are designed to detect light touch, near the surface.

Each receptor consists of free nerve endings either encapsulated within a tissue cell – such as with Ruffini's corpuscles (see annotations) – or unencapsulated and left loose. Sensory receptors can be roughly split into two main groups dependent on their rate of adaption (ie how fast the receptor adapts its frequency of action potentials/signals), with some slowly adapting and others rapidly adapting to external stimuli. Merkel's discs, for example, are slowly adapting, maintaining a high firing rate for a sustained period of time, delivering impulses to the brain for longer. Pacinian corpuscles, on the other hand, are rapidly adapting, quickly amending their firing rate depending on context (ie if a vibration is detected through the skin, which then stops, the Pacinian sensor stops sending signals to the brain quicker).

Under the skin



© Science Photo Library

Merkel's discs

Rough disc-shaped structures, Merkel's discs are located at the dermis-epidermis border and detect very faint touch and light pressure. The discs are the culmination of free neuron endings and consist of a Merkel cell in close apposition to an enlarged nerve terminal.

Free nerve endings

Often penetrating the epidermis, the free nerve endings react to heat and cold, allowing detection of temperature changes through the skin. Other endings are nociceptors (sensory receptors that send nerve signals to the spinal cord and brain) and detect pain.

Ruffini's corpuscle

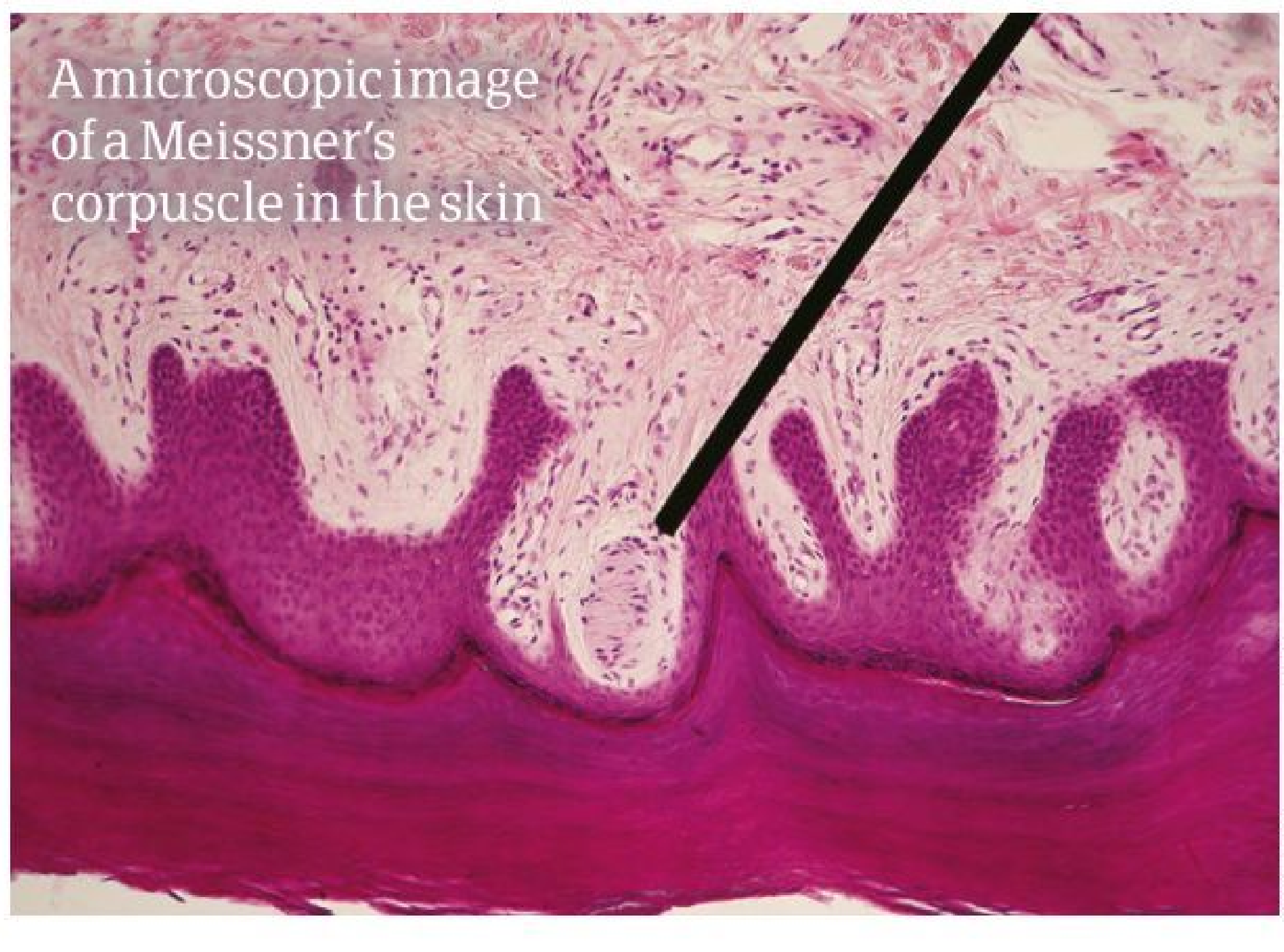
One of the skin's slowly adapting mechanoreceptors, Ruffini's corpuscles consist of a branching neuron ending surrounded by an oval-shaped capsule that detects the stretching of the skin and deep sustained pressure. When located in the fingertips, they also detect sliding, aiding grip.

Pacinian corpuscle

One of the largest mechanoreceptors, the Pacinian corpuscle is layered like an onion, and when deformed by outside forces it detects strongly sustained pressure. Interestingly, it can also detect rapid vibrations between ranges of 200-300Hz.

Meissner's corpuscle

Common to areas of highly sensitive, hairless skin – such as palms, fingertips, eyelids and lips – Meissner's corpuscles are rapidly adaptive enclosed receptors that are sensitive to faint touch and pressure. They have the highest sensitivity in detecting vibrations too, sensing ranges under 50Hz.



A microscopic image of a Meissner's corpuscle in the skin

© Wbensmith

SUBSCRIBE AND SAVE UP TO 61%

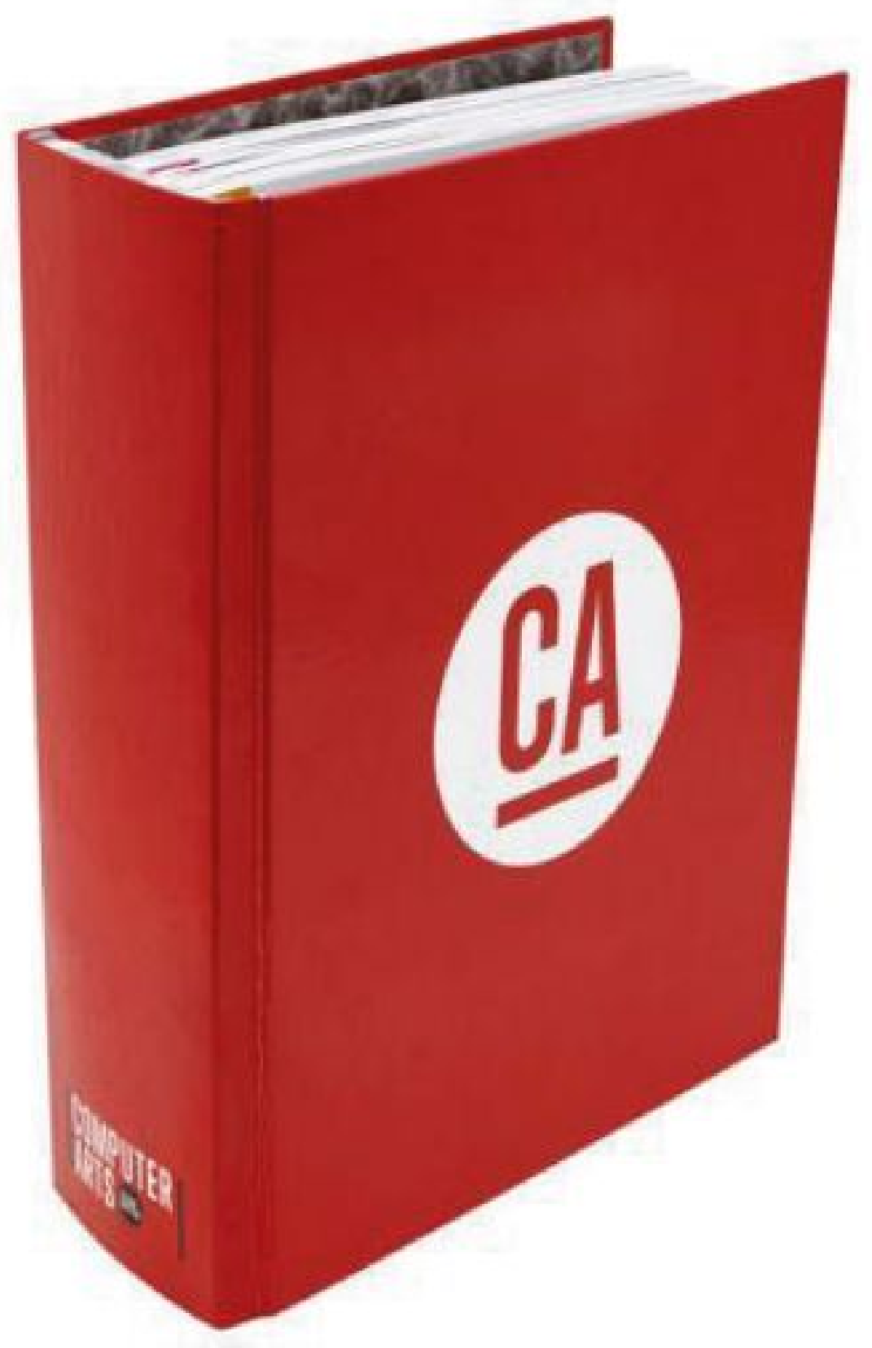
Every issue of your subscription, delivered direct to your door. Print & digital editions available.

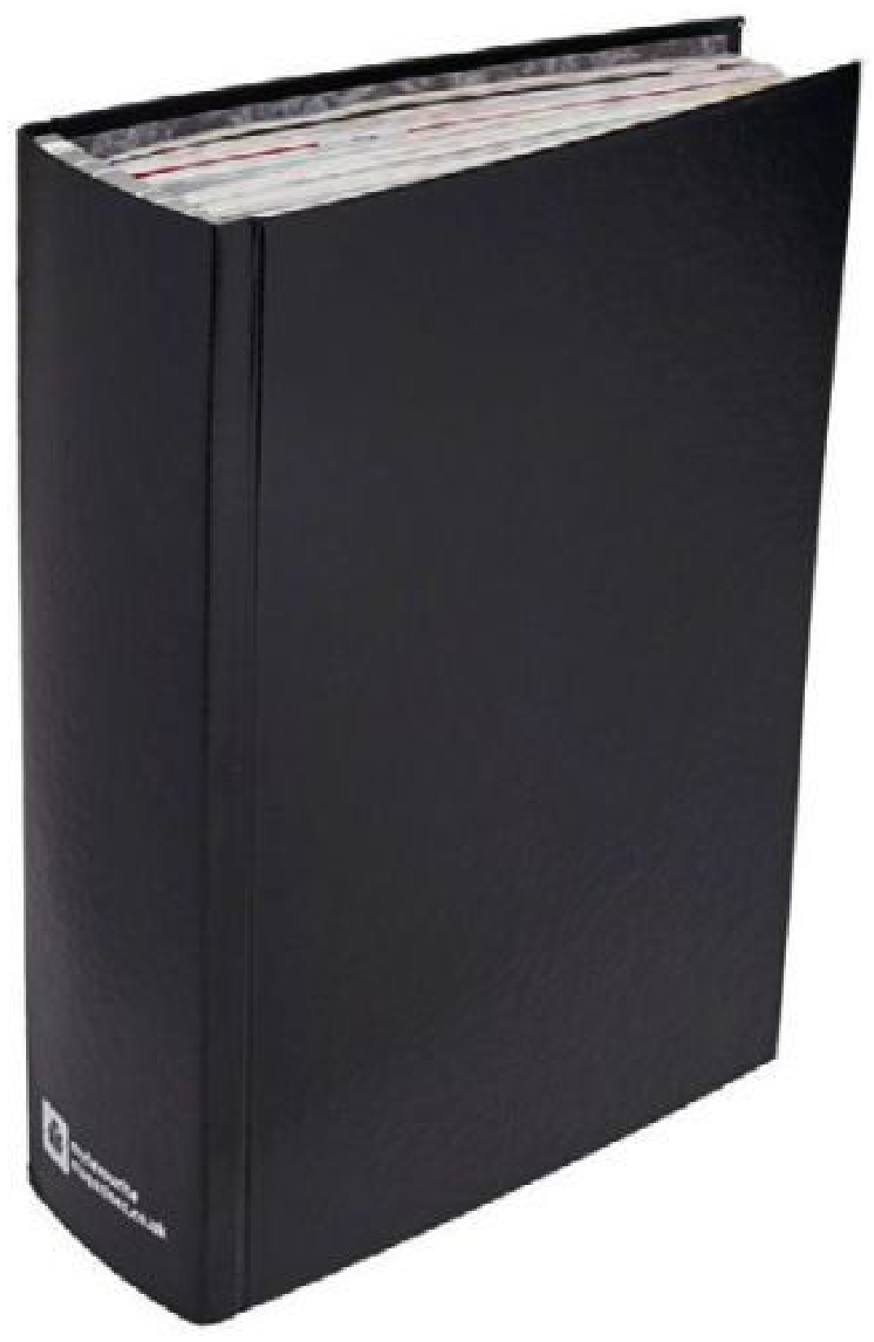
FourFourTwo
2018
EDGE
3D artist
LINUX FORMAT

NEAT STORAGE

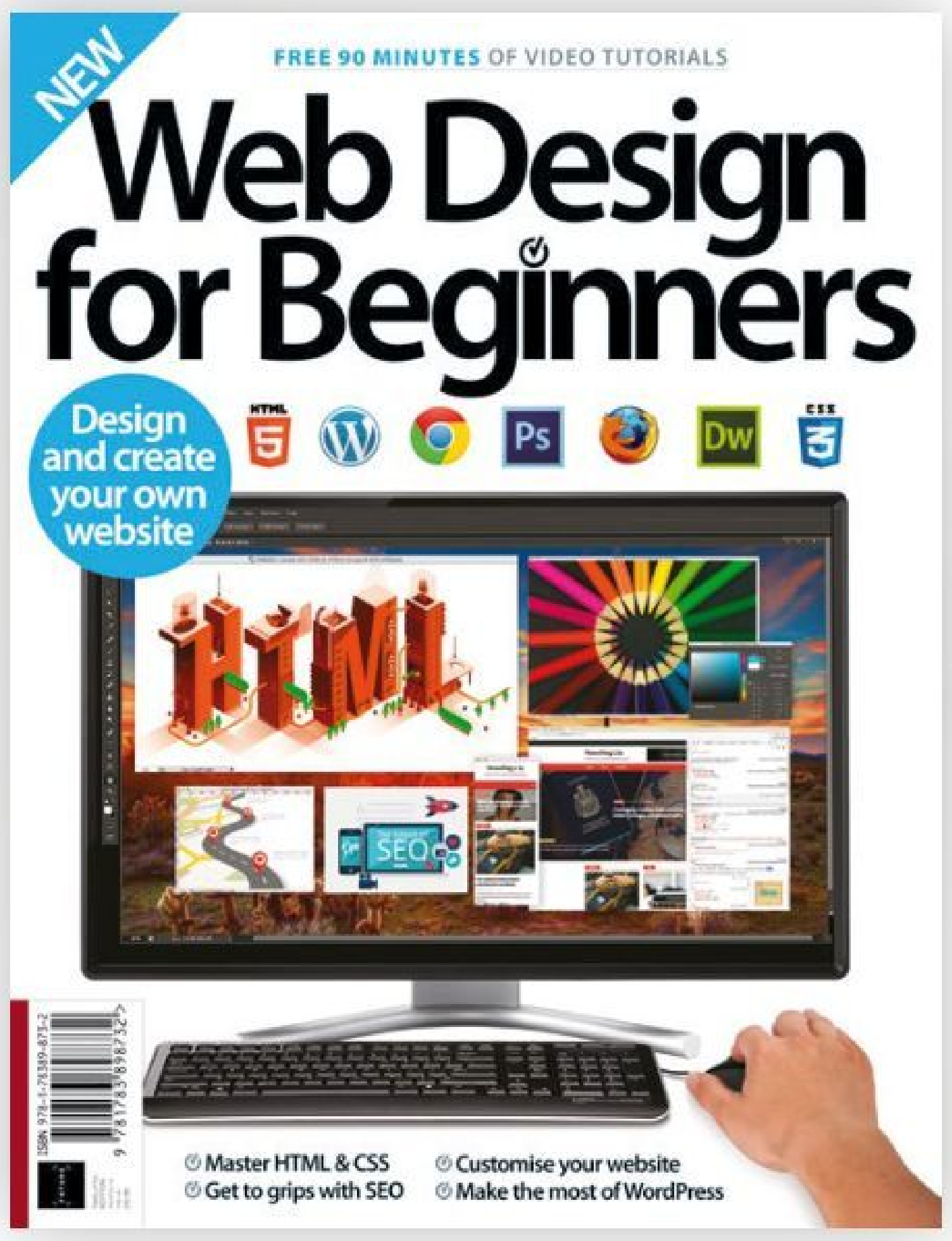
Store up to 13 issues of your magazine subscription in a coordinating slipcase or binder.

Digital Camera





myfavouritemagazines.co.uk


NEW
Web Design for Beginners

80s MOVIES
THE ULTIMATE CELEBRATION

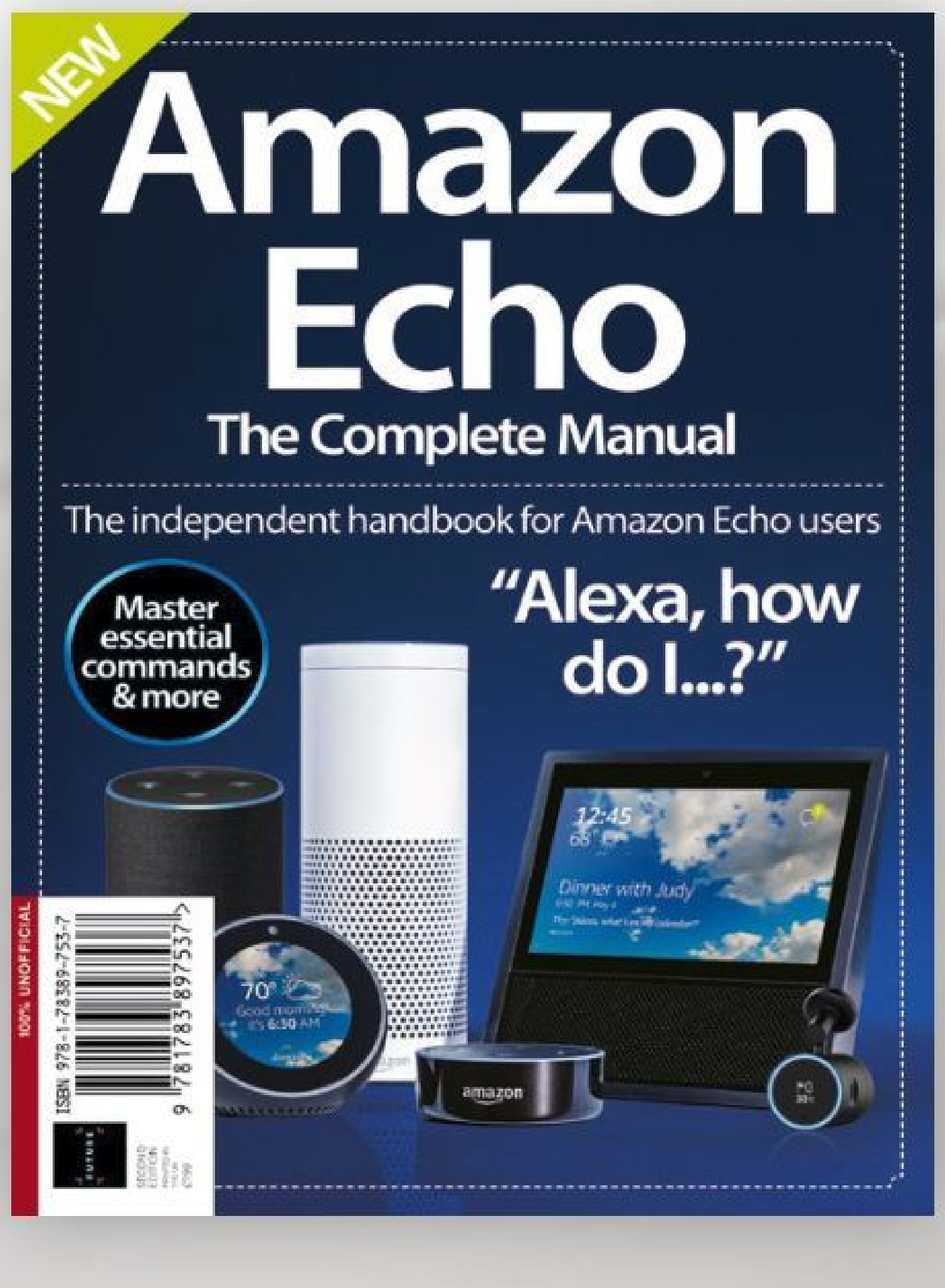
classic gaming
The ultimate guide to retro videogaming

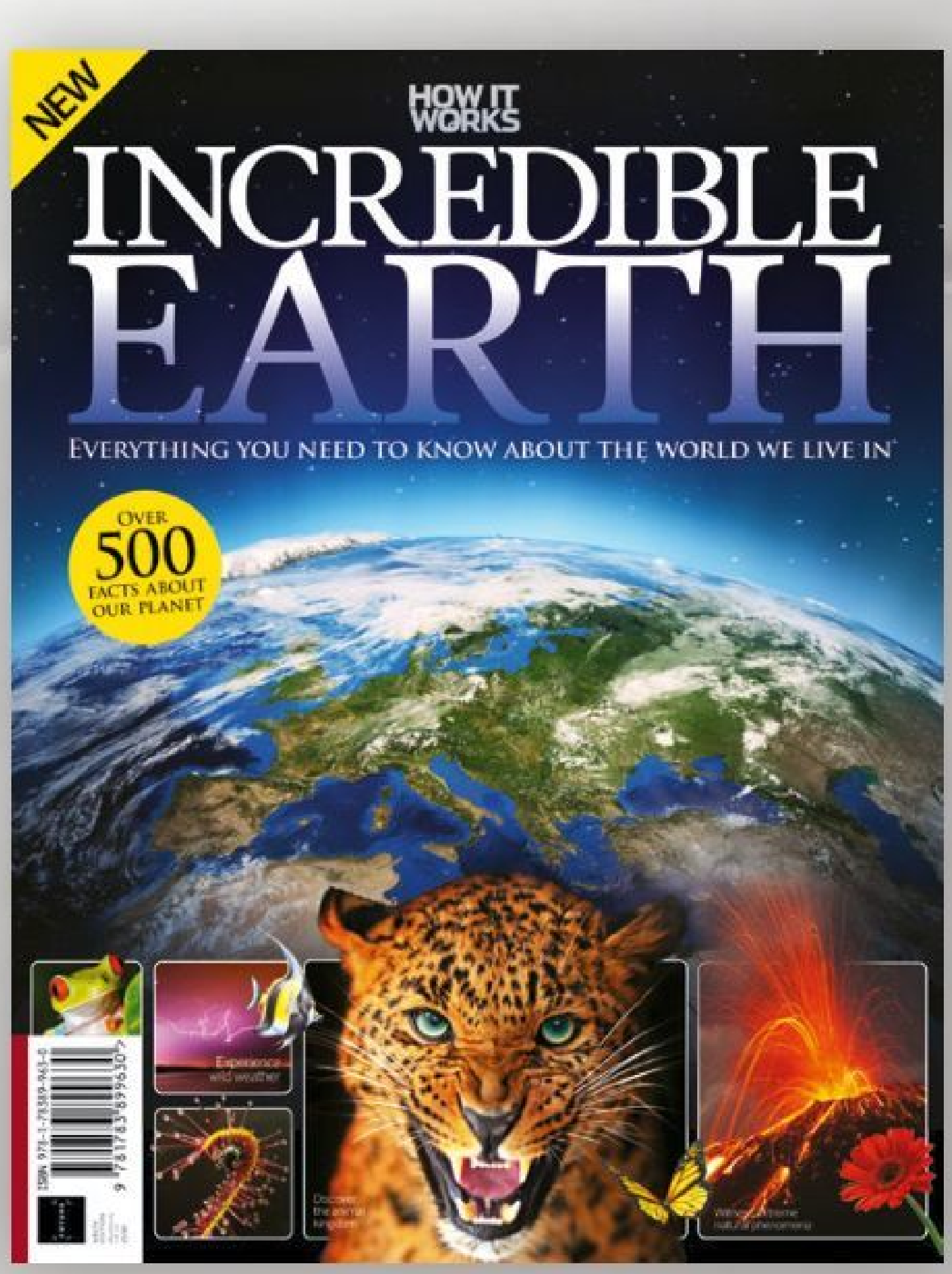
NEW
METALLICA

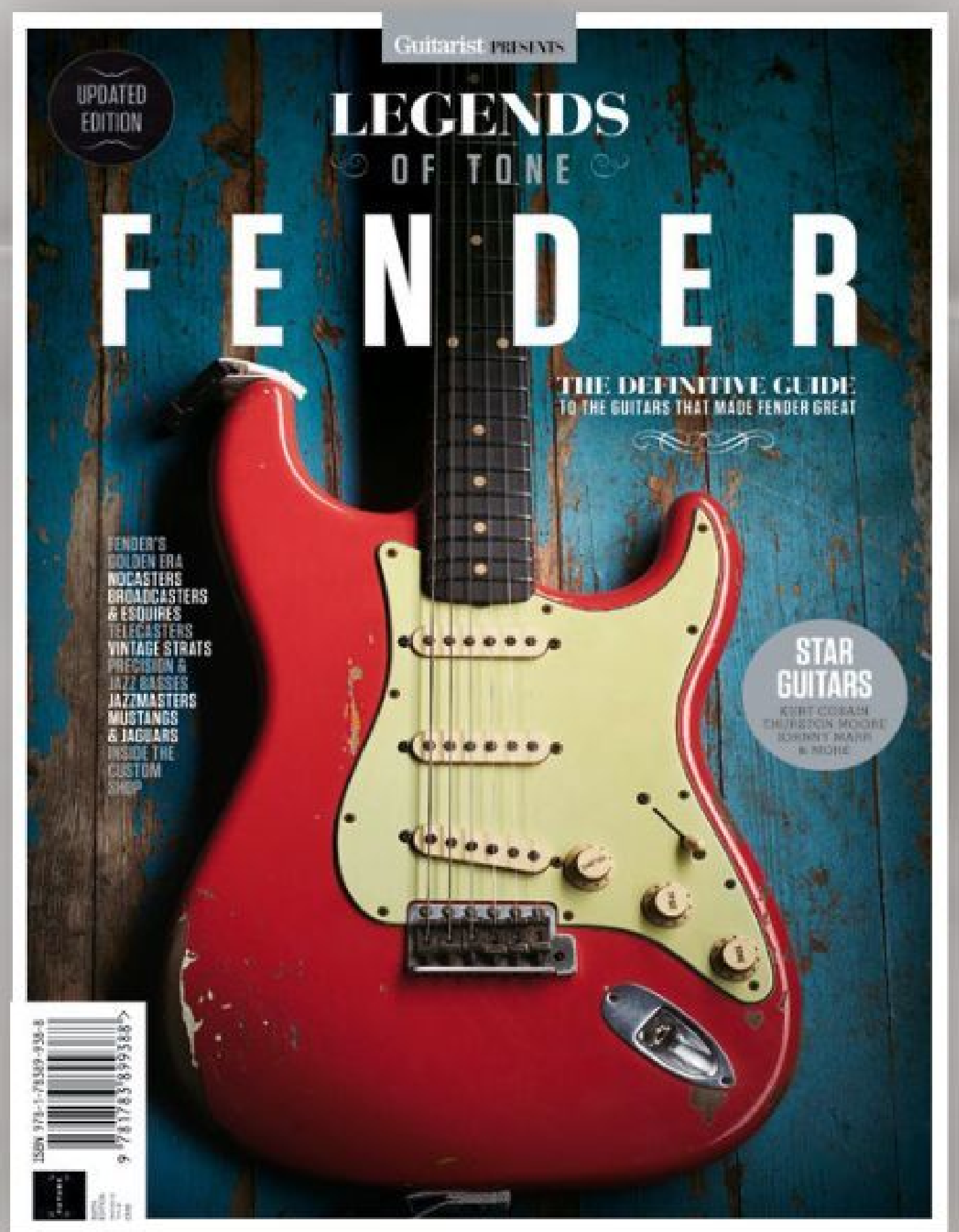
DISCOVER GREAT GUIDES & SPECIALS

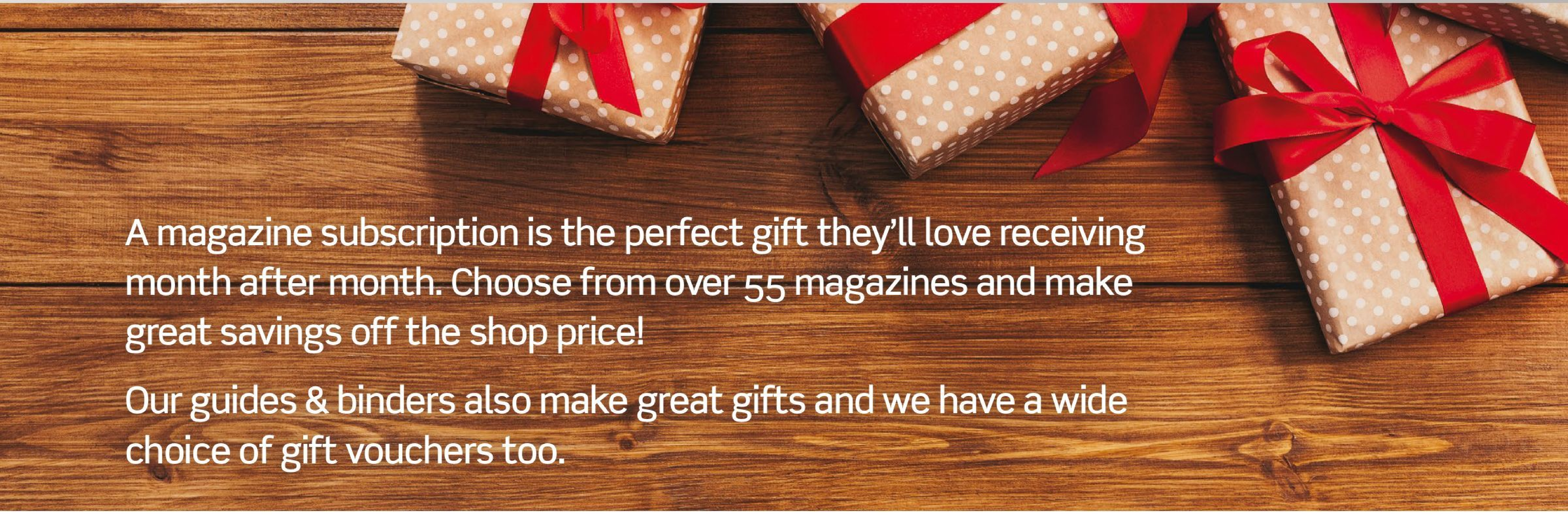
From photography to music and technology to gaming, there's something for everyone.

NEW
The Black & White Photography Book


NEW
Amazon Echo
The Complete Manual


NEW
INCREDIBLE EARTH


LEGENDS OF TONE
FENDER



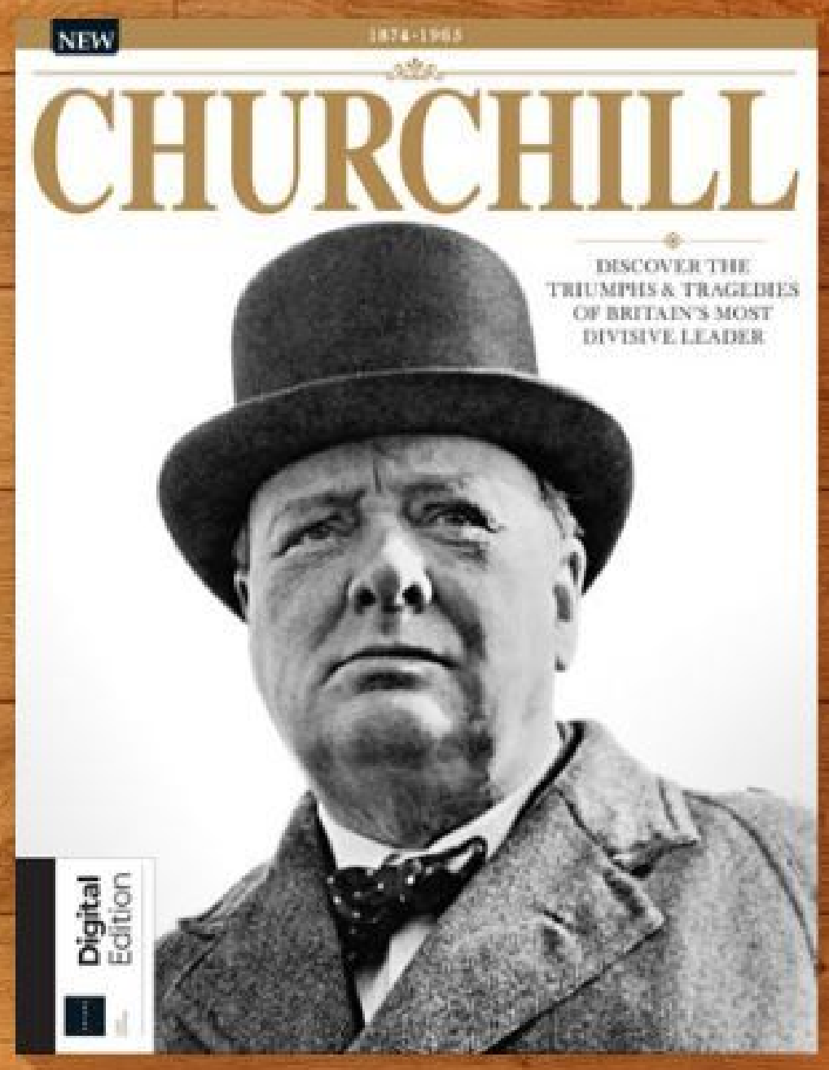
A magazine subscription is the perfect gift they'll love receiving month after month. Choose from over 55 magazines and make great savings off the shop price!

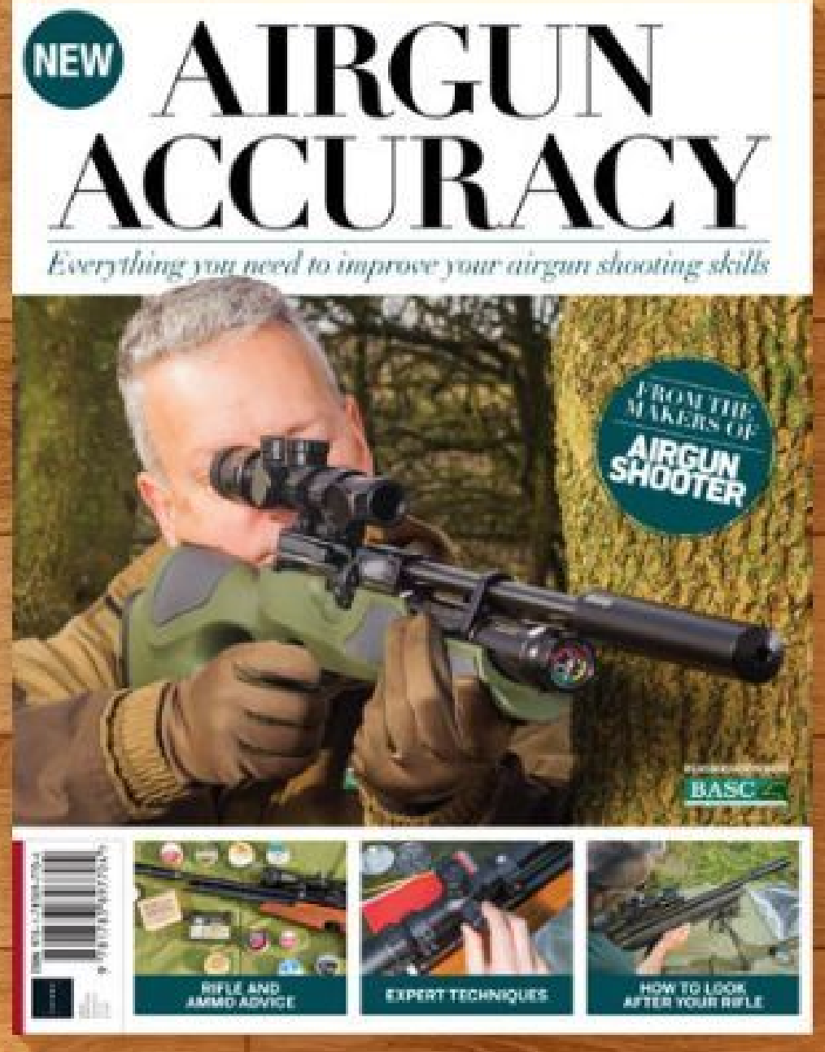
Our guides & binders also make great gifts and we have a wide choice of gift vouchers too.

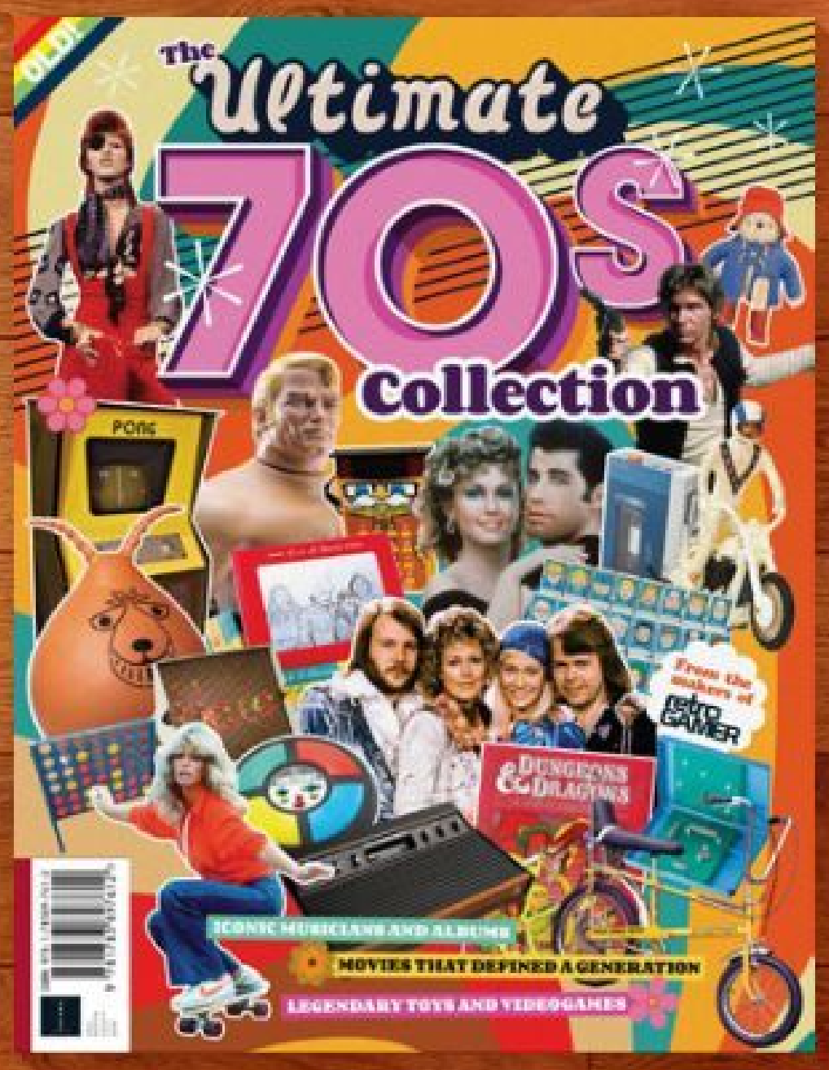
✓ No hidden costs Shipping included in all prices We deliver to over 100 countries Secure online payment

FUTURE

myfavouritemagazines
Official Magazine Subscription Store

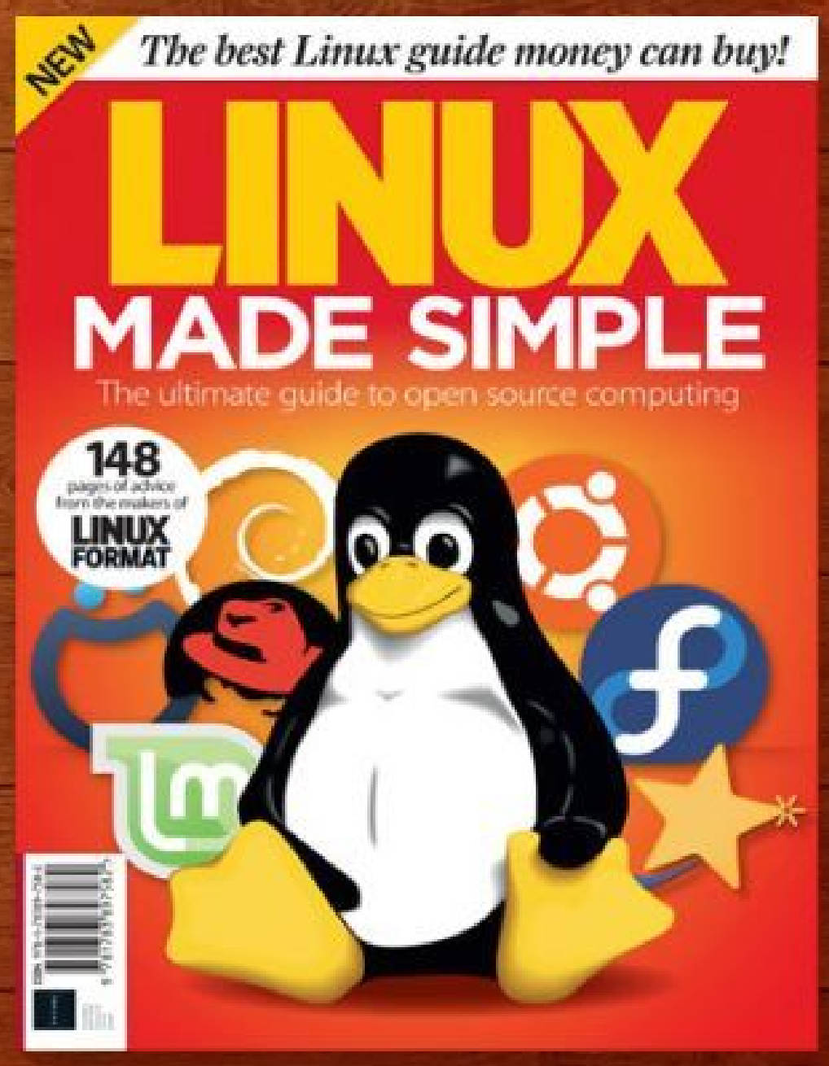


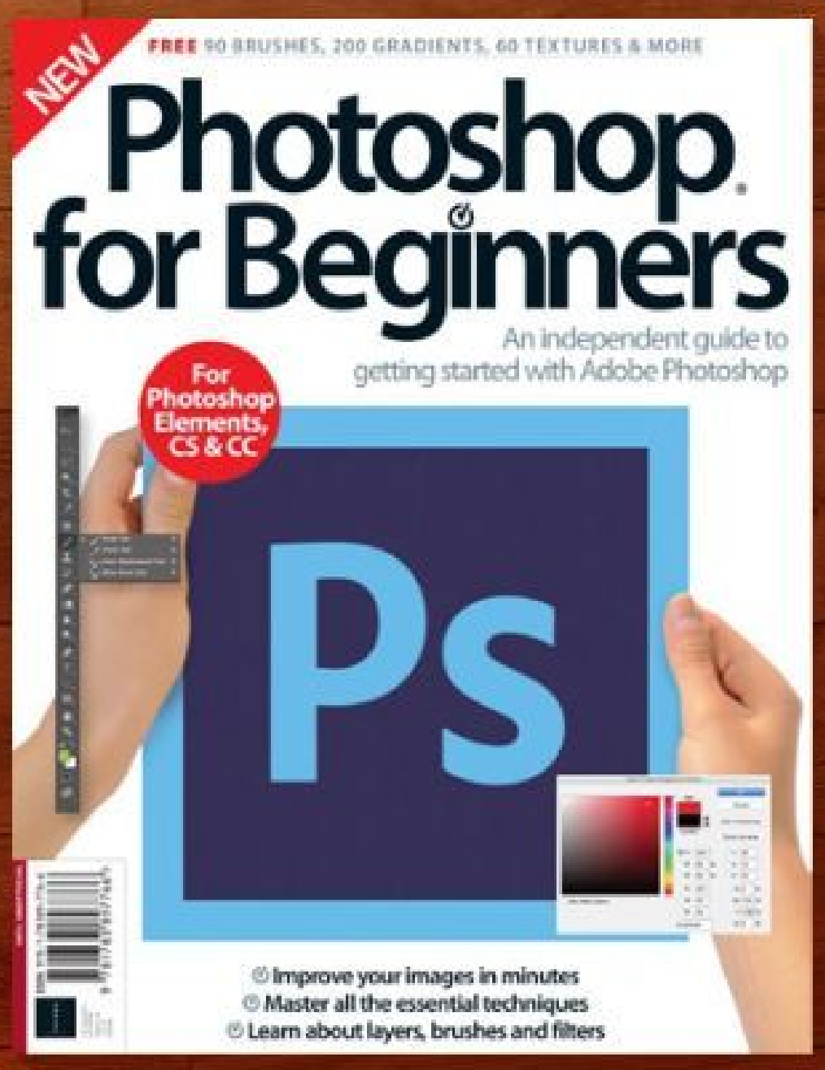


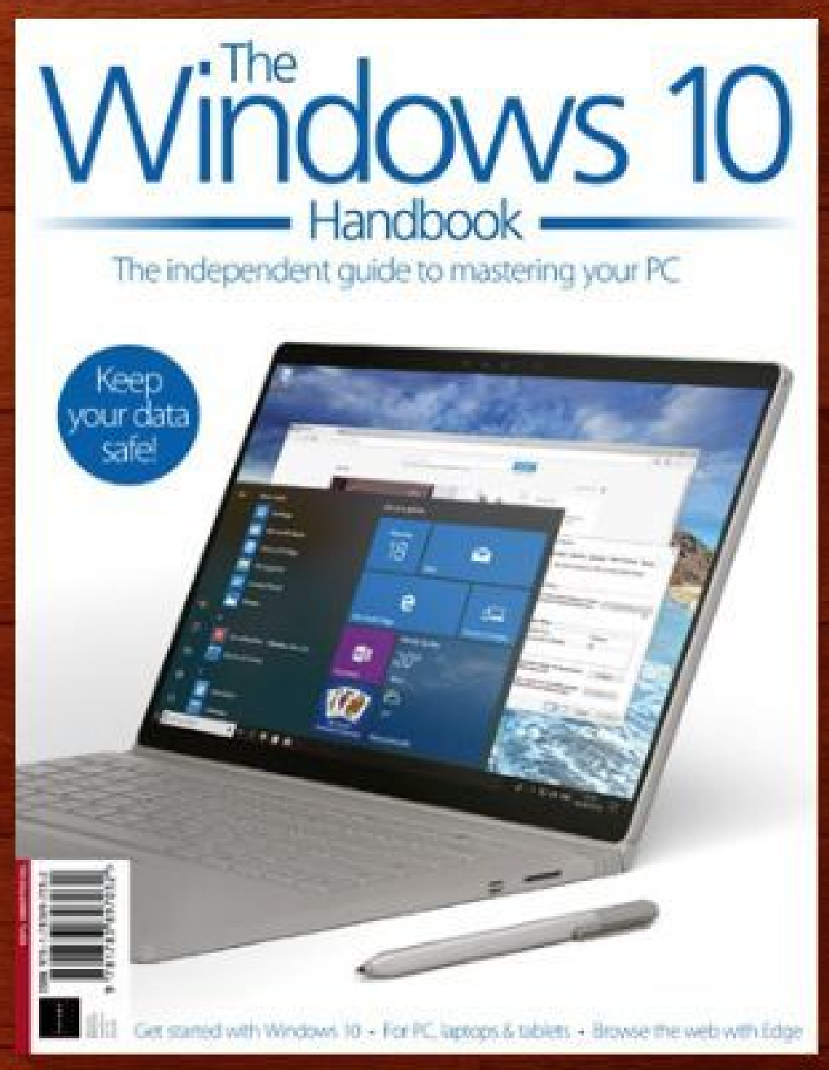
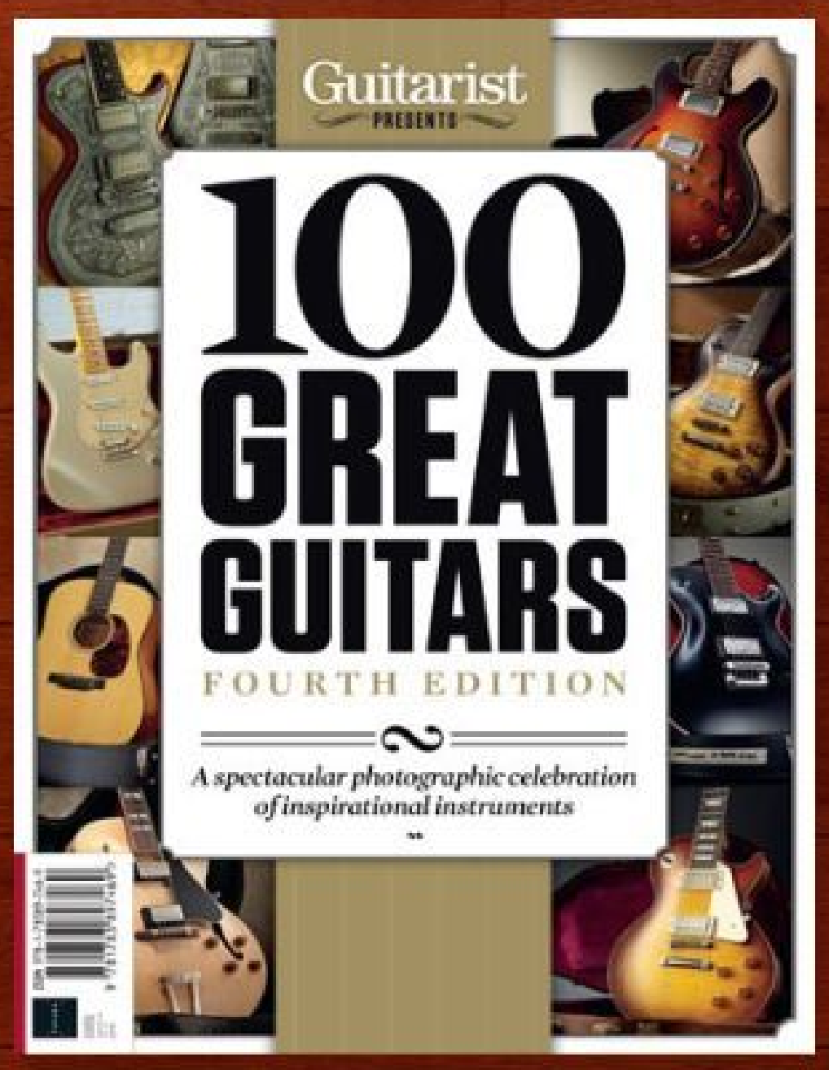


Discover another of our great bookazines

From science and history to technology and crafts, there are dozens of Future bookazines to suit all tastes





✓ Get great savings when you buy direct from us

✓ 1000s of great titles, many not available anywhere else

✓ World-wide delivery and super-safe ordering

FUTURE

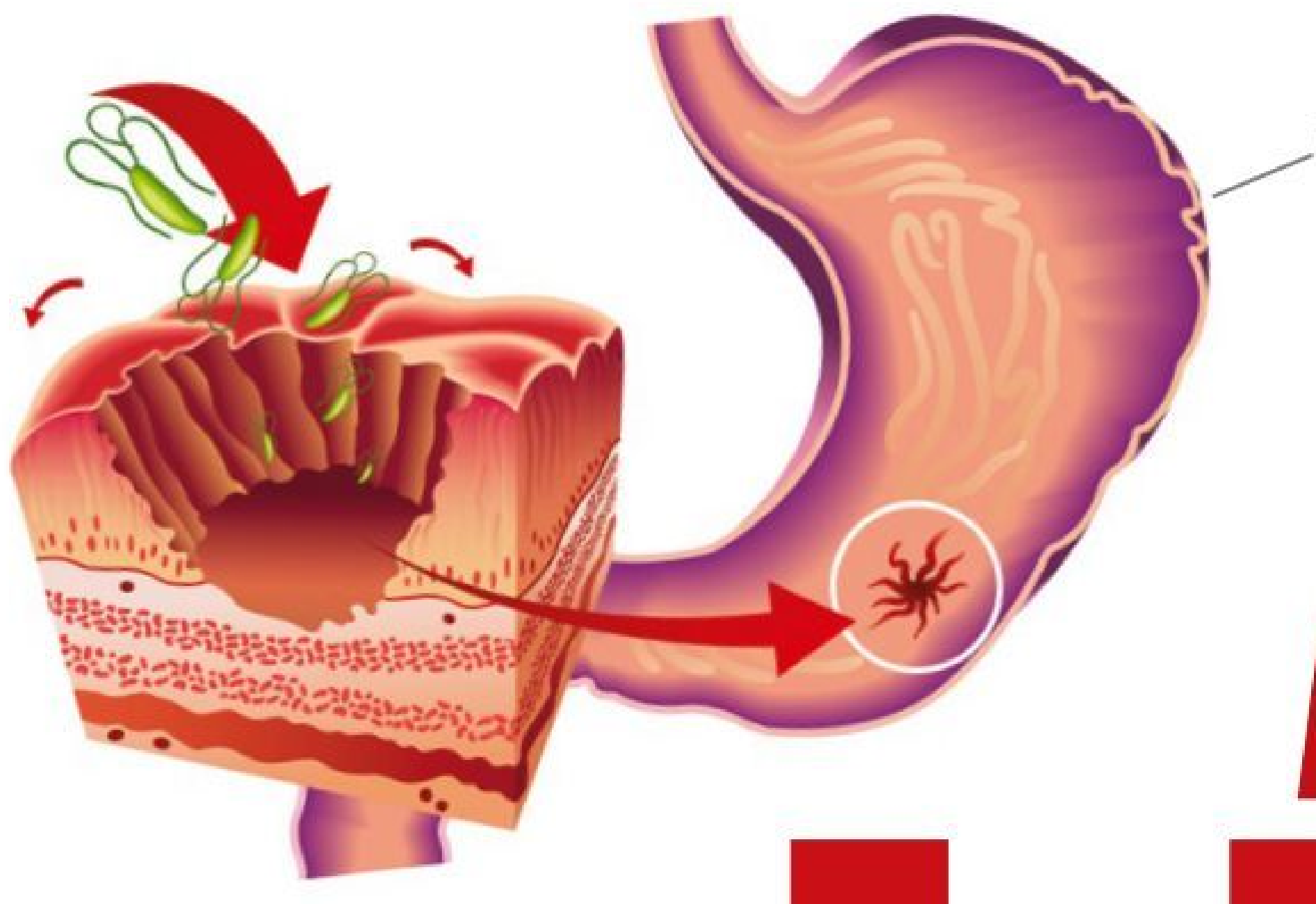
www.myfavouritemagazines.co.uk

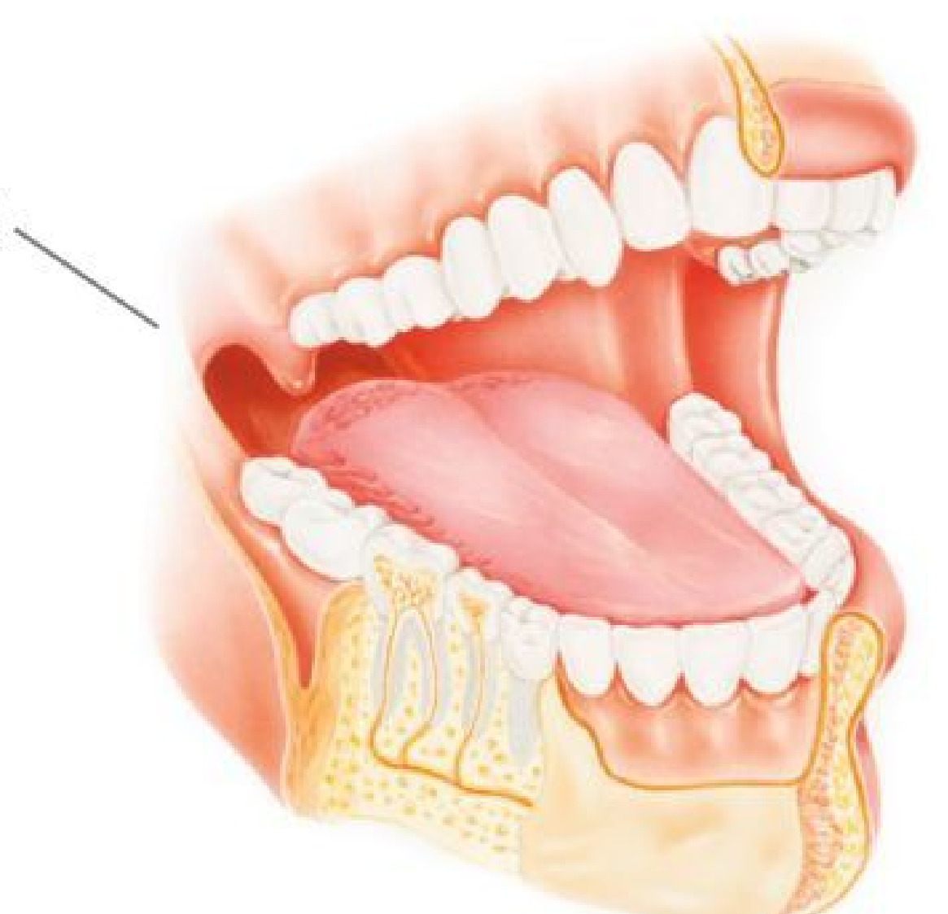
Magazines, back issues & bookazines.

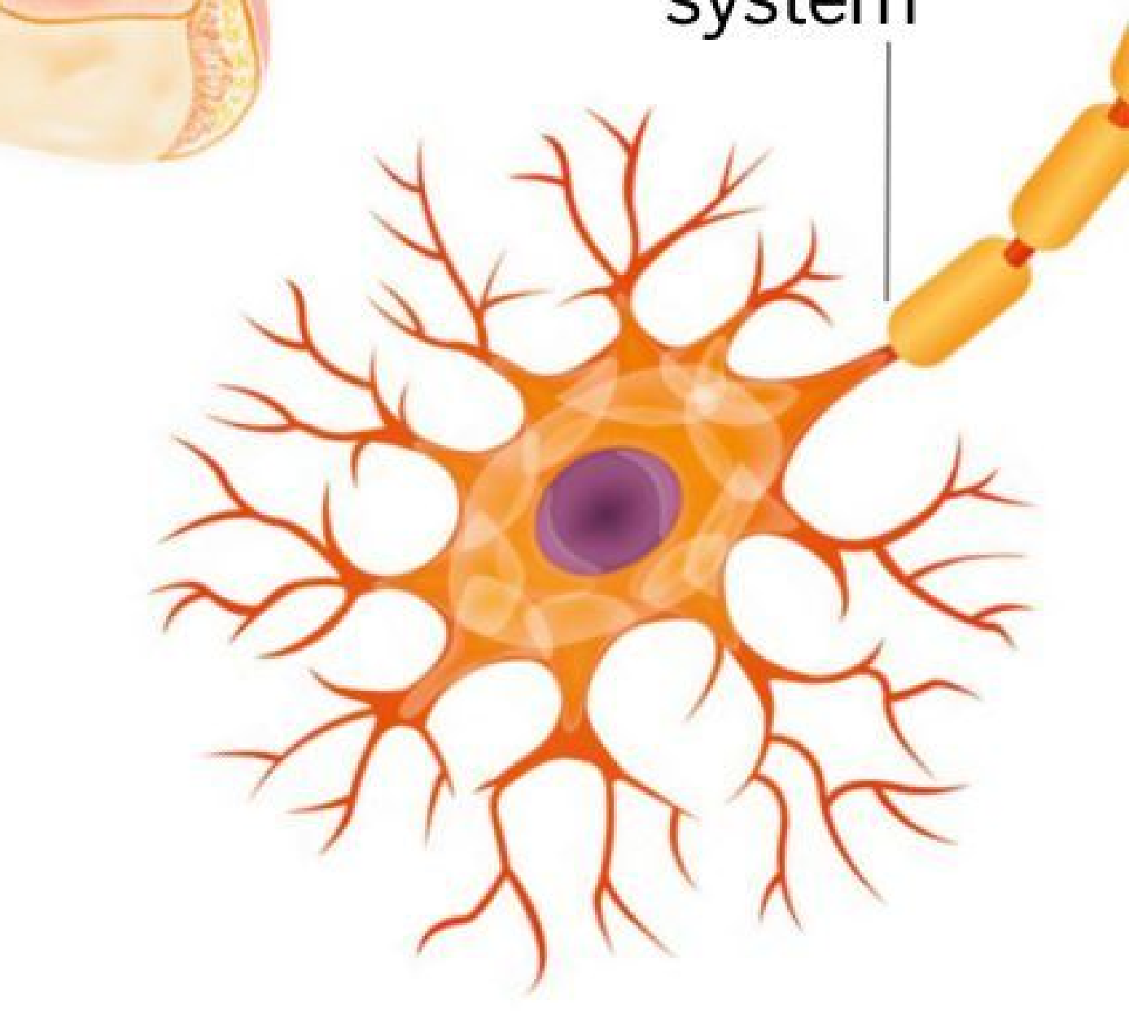
HOW IT WORKS

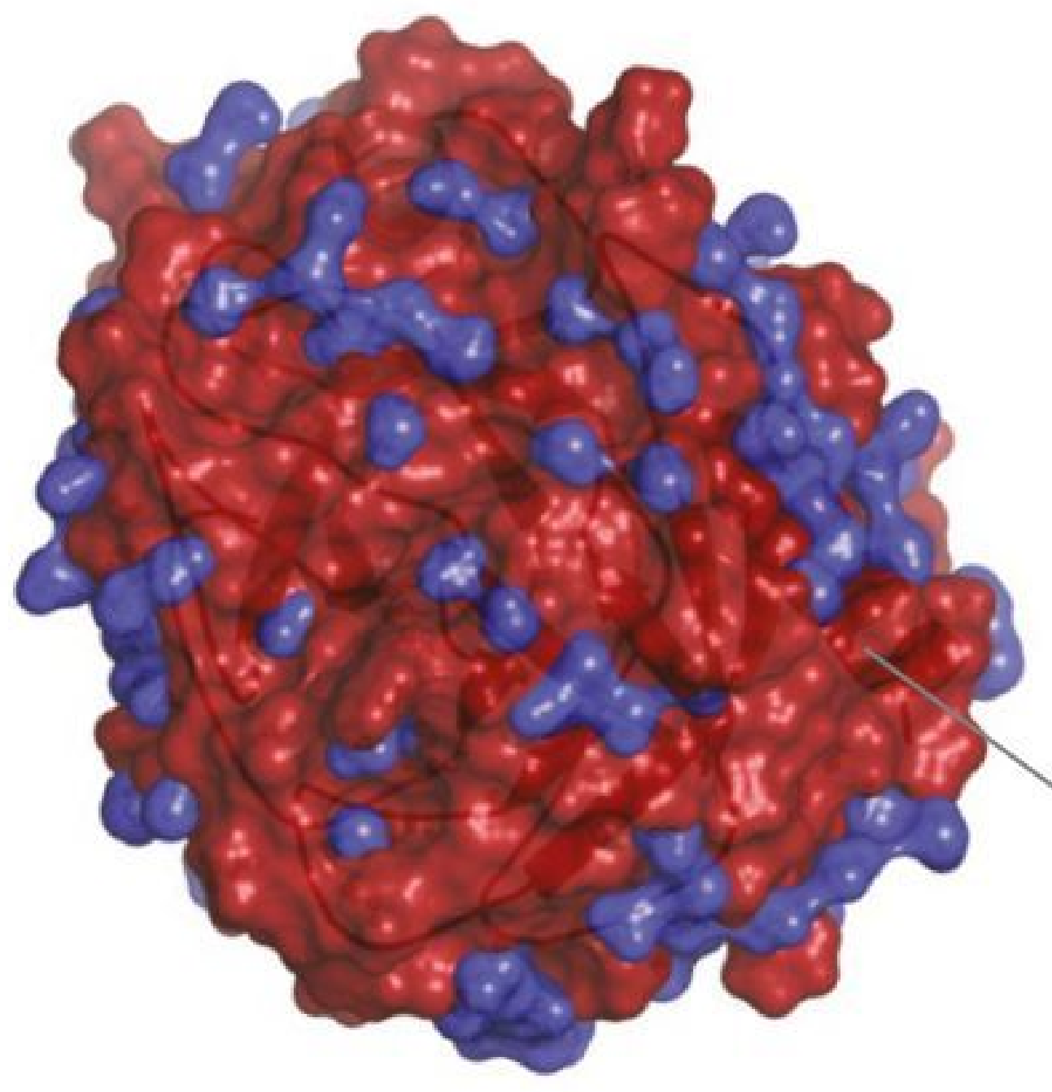
INSIDE THE HUMAN BODY

160+ PAGES OF FASCINATING FACTS

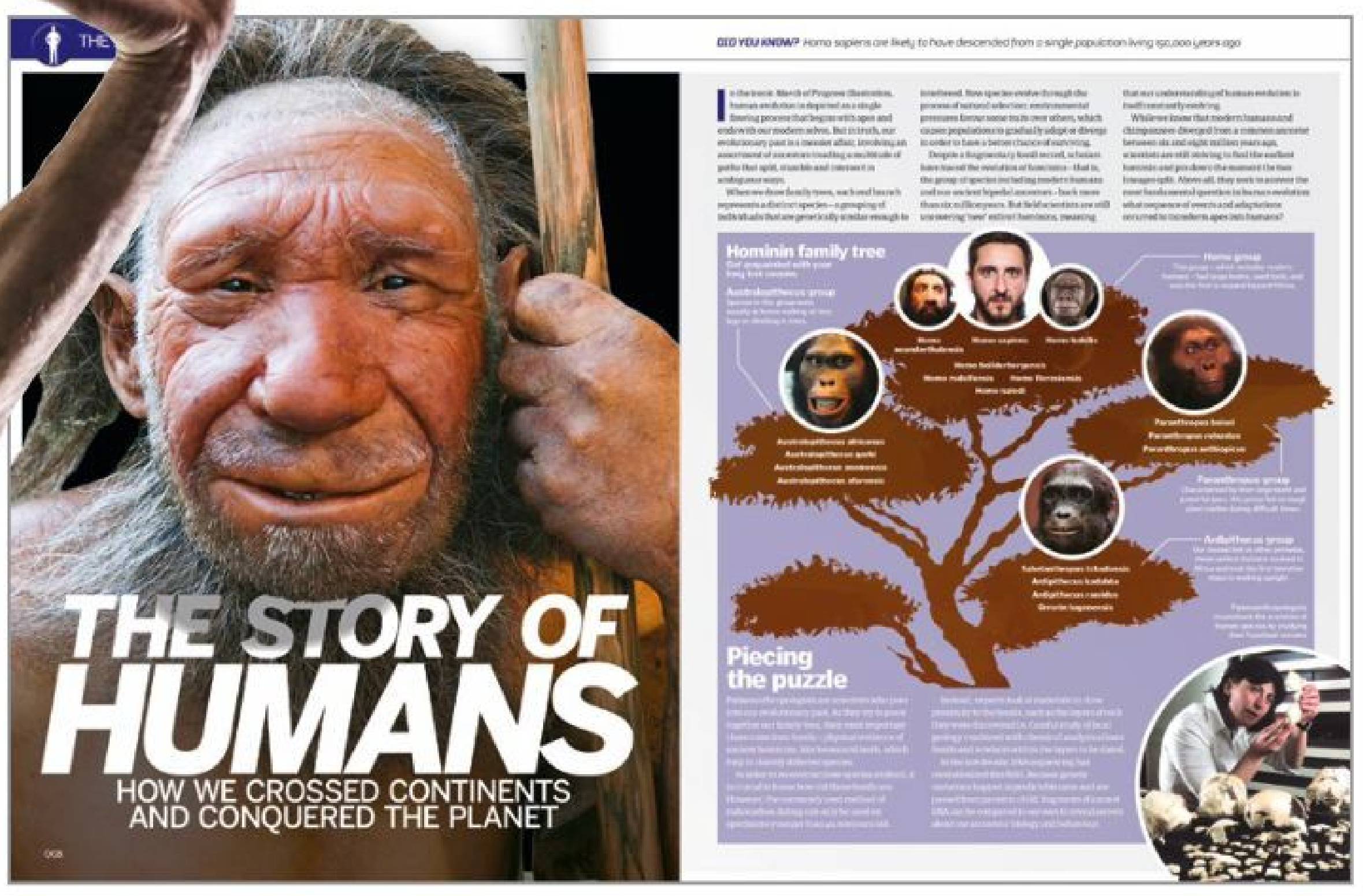

What goes on inside our stomachs?


How do we swallow?


The body's nervous system


The digestive system

How does exercise increase muscle strength?


THE STORY OF HUMANS

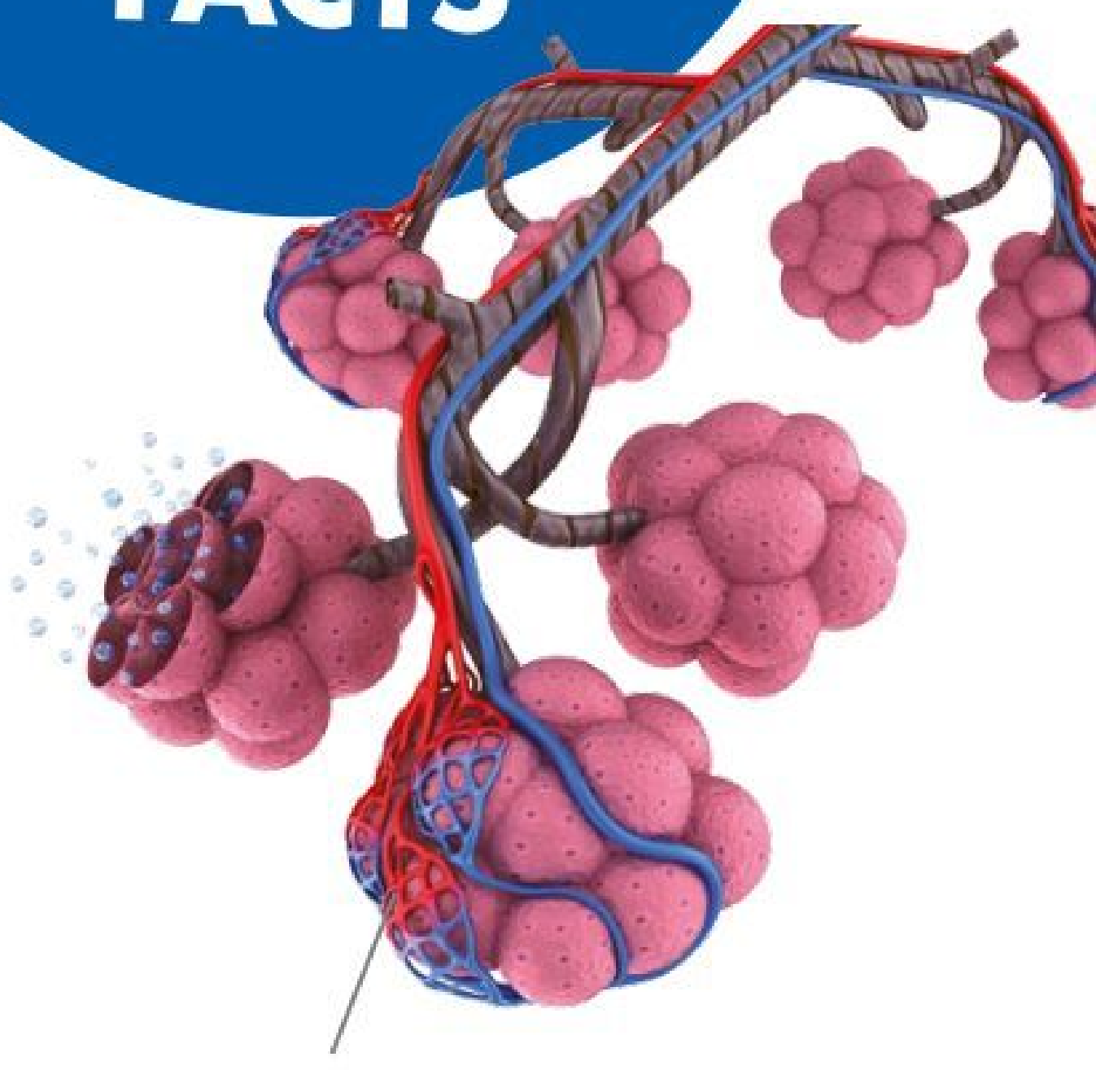
HOW WE CROSSED CONTINENTS AND CONQUERED THE PLANET

Hominin family tree

Piecing the puzzle

YOUR FIRST YEAR

What happens to the human body in the first 12 months of life

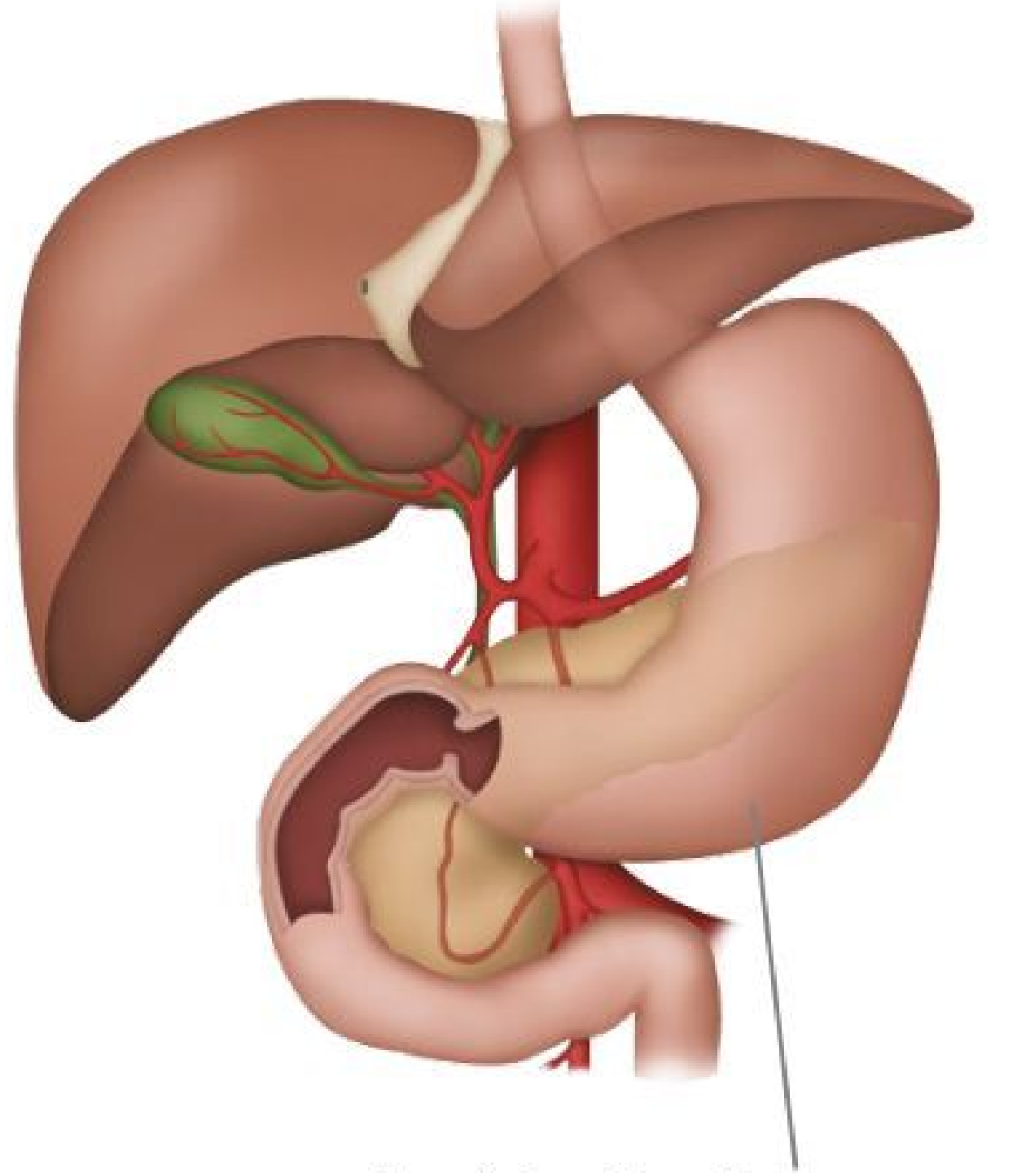

The respiratory system

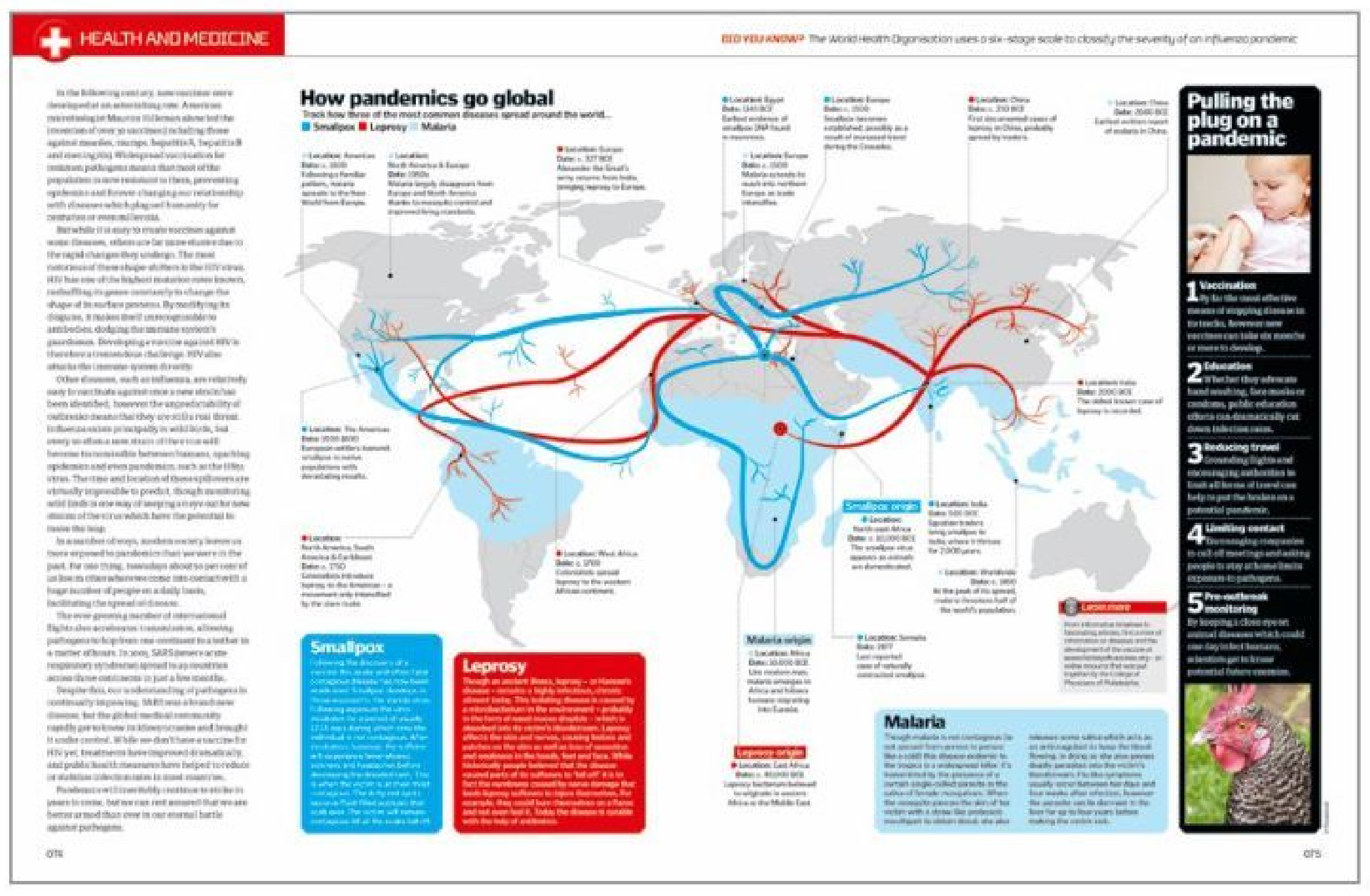
The story of humans

Learn about the birth of the human race and how we've evolved and adapted to our changing surroundings

What are we made of?

Get under the skin of the human body – discover the secrets of its essential organs and how they work


Inside the liver and pancreas


How pandemics go global

Pulling the plug on a pandemic

Smallpox

Leprosy

Malaria

FOOD & YOUR BODY

Join us as we unravel all nine metres of your digestive system

Journey of your food

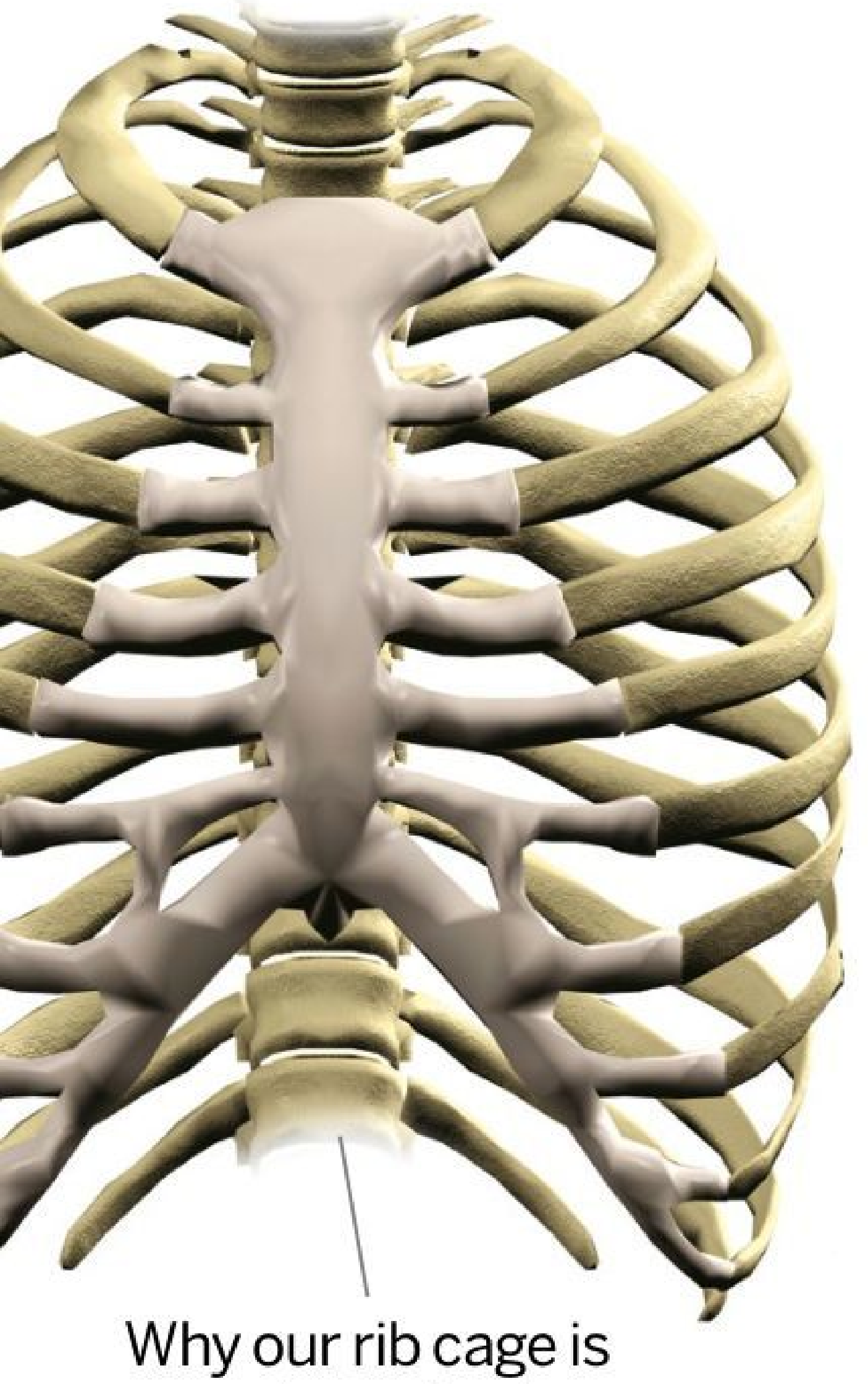
Food chain

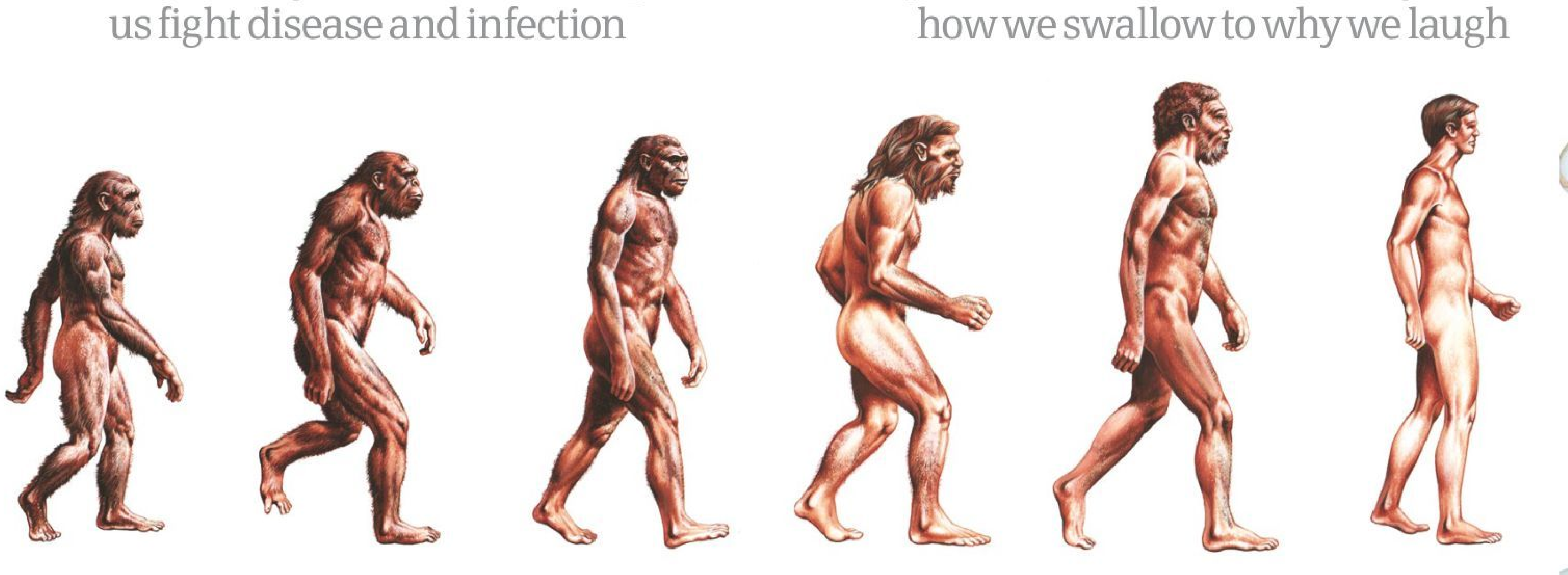
Health & medicine

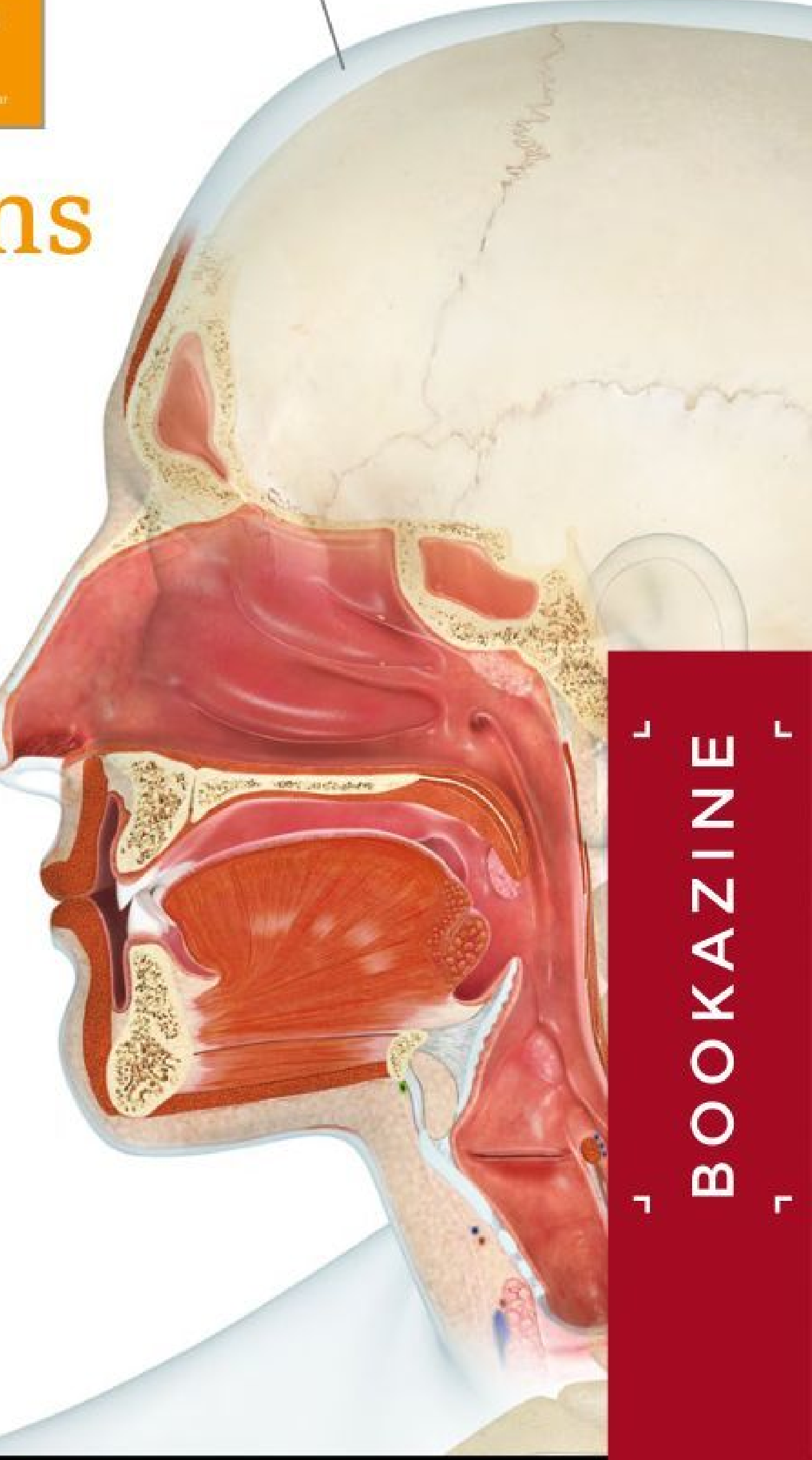
Find out how a combination of the human body and medicine help us fight disease and infection

Processes & bodily functions

Explore the weird and wonderful processes of the human body, from how we swallow to why we laugh


Why our rib cage is so important




The human head

BOOKAZINE

TAKE A TOUR OF YOUR ANATOMY WITH OUR HEAD-TO-TOE GUIDE